

South Dakota State University

## Open PRAIRIE: Open Public Research Access Institutional Repository and Information Exchange

---

Agronomy, Horticulture, and Plant Science Books

Department of Agronomy, Horticulture, and Plant  
Science

---

2012

# iGrow Wheat: Best Management Practices for Wheat Production

David C. Clay

*South Dakota State University*, david.clay@sdstate.edu

C. Gregg Carlson

*South Dakota State University*, Gregg.Carlson@sdstate.edu

Kevin Dalsted

*South Dakota State University*

Follow this and additional works at: [https://openprairie.sdstate.edu/plant\\_book](https://openprairie.sdstate.edu/plant_book)



Part of the [Agricultural Science Commons](#), [Agriculture Commons](#), and the [Agronomy and Crop Sciences Commons](#)

---

### Recommended Citation

Clay, David C.; Carlson, C. Gregg; and Dalsted, Kevin, "iGrow Wheat: Best Management Practices for Wheat Production" (2012). *Agronomy, Horticulture, and Plant Science Books*. 1.  
[https://openprairie.sdstate.edu/plant\\_book/1](https://openprairie.sdstate.edu/plant_book/1)

This Book is brought to you for free and open access by the Department of Agronomy, Horticulture, and Plant Science at Open PRAIRIE: Open Public Research Access Institutional Repository and Information Exchange. It has been accepted for inclusion in Agronomy, Horticulture, and Plant Science Books by an authorized administrator of Open PRAIRIE: Open Public Research Access Institutional Repository and Information Exchange. For more information, please contact [michael.biondo@sdstate.edu](mailto:michael.biondo@sdstate.edu).



## CHAPTER ONE

# Sustainable Production of 100-Bushel Wheat

*Bob Fanning* ([Robert.Fanning@sdstate.edu](mailto:Robert.Fanning@sdstate.edu))

*Bill Ferguson* ([fergfarm@gwtc.net](mailto:fergfarm@gwtc.net))

Reaching 100-bu/acre routinely will take compiling the collective wisdom of professional agronomists and farmers alike. This chapter represents a starting point. Hints for reaching this goal are provided in Table 1.1. Each of these topic areas is addressed in this chapter—as well as related chapters throughout the book.

**Table 1.1. Hints to produce 100 bu/acre.**

- Pay attention to the details.
- Use high quality seed and plant a uniform stand with good disease and lodging resistance at an appropriate rate.
- Use soil sampling to monitor soil nutrients and try to return more nutrients than those removed in the harvested grain.
- Consider a split application of N to minimize lodging and improve wheat quality.
- Control pests in a timely manner.
- Scout and apply fungicides as needed.
- Minimize yield losses during combining.
- Adopt practices that increase the length of the grain filling period.
- Plant field peas prior to wheat and use rotations to reduce disease, insect, and weed problems.



### ***Sustainability and meeting food production goals***

The long-term sustainability of the South Dakota wheat industry depends upon profitability, soil and water stewardship, and the personal satisfaction experienced by growers. The “optimization of wheat production” and the “sustainability of the wheat industry” are interlinked and are much more than yield alone. Obtaining sustainable wheat production requires a personal commitment by a producer to manage production for long-term profitability, which may be different than short-term maximum production. Long-term profitability is heavily dependent upon a producer’s care for the soil and water resources. Maintaining soil health involves management to maintain or increase soil organic matter, a stable and well-aerated soil structure, and an active microbe population, all while minimizing the conditions that lead to soil erosion.

Management options such as crop rotations, genetics, pest control, tillage, cover crops, and fertility all impact long-term productivity and the ability to optimize yields for a given environment or a soil landscape. Optimizing wheat production in South Dakota is dependent upon producers making good management choices for the sustainability of their individual farms and the state’s wheat industry.

### ***Growing 100 bu/acre wheat***

As human populations increase, producers must seek ways to economically push yields to higher levels. Growing wheat for yields that exceed 100 bu/acre will involve close attention to details. One practice by itself will not achieve high yields. We believe that routinely achieving 100 bu/acre requires the adoption of a systematic and advanced production program.

Weekly or biweekly scouting is necessary to monitor weeds, insects, diseases, and nutrient deficiencies.

As the crop progresses through the growing season, circumstances may either justify, or make impractical, additional inputs or practices that could further enhance yield. A list of key management practices needed to achieve 100+ bu/acre wheat yields are discussed in other chapters of this book.



**Figure 1.1. A wheat field with a very high yield potential.** Producing fields that look like this requires an attention to details.

### ***Crop rotations***

A long-term crop rotation offers diversity, both in terms of crop type (cool or warm season, grass or broadleaf, nitrogen fixing or nitrogen consuming, tap or bunch root type) and water use intensity (length of time using water). Diversity disrupts disease, insect and weed cycles, and it may improve soil quality. Including high residue crops in the rotation, such as

corn, helps build organic matter, which, in turn, helps to improve the resilience of the entire system. Wheat following field peas often out-yields wheat following wheat. Carr et al. (2005) reported that wheat or barley yields were increased by 20% when following field peas rather than small grains. The reason for this rotational effect is not well understood.

### ***Variety selection***

SDSU and other wheat breeders are continuously releasing varieties with enhanced yields as well as improved insect and disease resistance. For current information, obtain the most recent copy of SDSU publication EC774, “Small Grains Variety Recommendations” or ExEx8136, “Winter Wheat Variety Yield Results and Planting Tips” at your local Regional Extension Office. Information on disease resistance is available in Hall et al. (2010) or on-line at: [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/EC774-11.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC774-11.pdf).

Results are listed by testing location and are summarized by region and state so producers can select varieties that perform well in their area. Most crop performance testing (CPT) plots are managed for moderate yield potential regarding planting rate, fertility and weed control without fungicide applications so as to evaluate impact of foliar diseases on the variety yields. On occasion, a foliar fungicide application is made to protect against Fusarium head blight.

### ***Seed source***

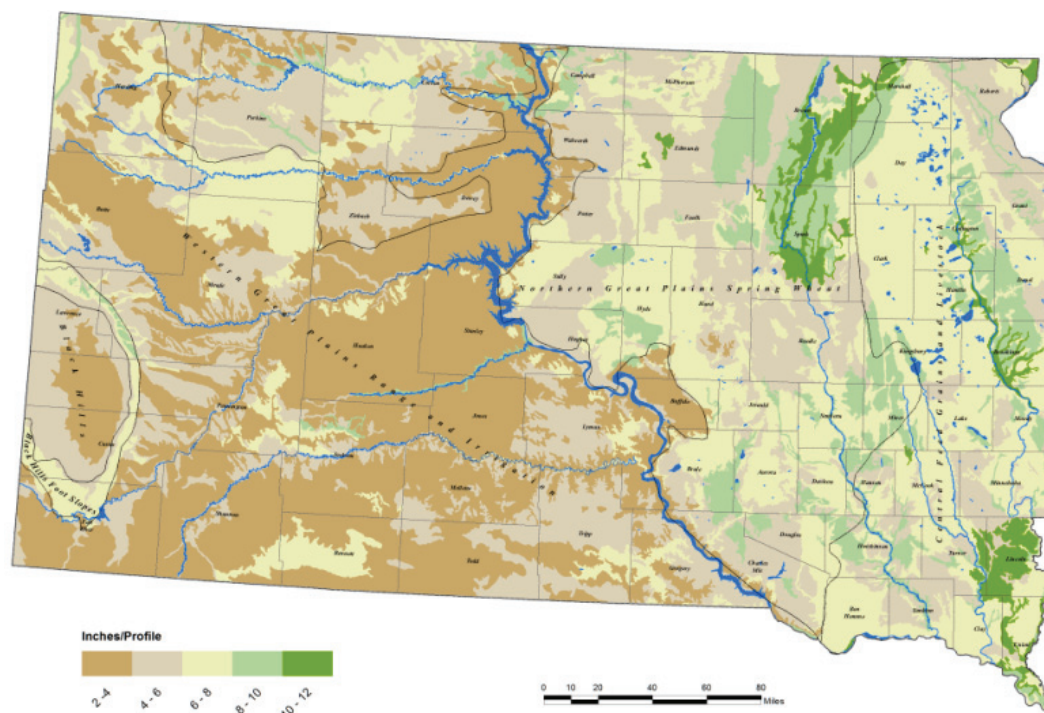
Certified seed is a source of clean, disease-free seed of a known germination percentage, and it is guaranteed to be free of noxious weed seeds. Planting certified seed ensures that farmers are using seed that is genetically pure and has the highest yield potential.

### ***Seedbed***

One of the goals of tillage is to provide a seedbed that favors quick germination and early plant growth while maintaining soil moisture as close to field capacity as possible. Improvements in planting equipment, such as no-till drills, as well as the development of disease tolerant cultivars and herbicides, which can be applied post-emergent rather than preplant, have made many tillage practices unnecessary. In South Dakota no-tillage has been adopted on over four million acres. When using no-till practices, seedbed preparation begins at harvest of the previous crop. The previous crop residue ideally should be chopped and uniformly spread across the width of the combine’s header swath. Additional details for seedbed preparation using no-tillage are available in Beck et al. (2009).

### ***Optimize available water***

The ability of the soil to store and provide water has a large impact on the soil’s productivity. In many locations, fall and spring rainfall are stored in the soil until the plant utilizes it. A map showing the potential of the soil to store water is provided in Figure 1.2. Soil surveys are available for all South Dakota counties. As a rule of thumb, the greater the soil profile moisture-holding capacity, the greater is the yield potential of that soil, assuming adequate drainage.



**Figure 1.2. Map of soil water holding capacity for South Dakota.**

(Reitsma, K.D., 2011. South Dakota State University, Plant Science Department. Source of Data: Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. U.S. General Soil Map (STATSGO2). Available online at <http://soildatamart.nrcs.usda.gov>. Accessed [May 16, 2011]).

### ***Planting date***

Adopting management practices that increase the length of the grain filling period is critical for increasing yields. For example, planting spring wheat early at uniform planting distances reduces competition between adjacent plants and allows heading and flowering to occur earlier, avoiding the hottest weather of summer.

Winter wheat should be established before freezing temperatures to attain cold tolerance and accumulate energy reserves for the following spring. Winter wheat planted too early can have disease problems, while if planted too late it can suffer from winterkill. Due to climatic variability, the optimum planting date will vary.

### ***Seeding rate***

Seeding rates are dependent on the variety and soil productivity. On a producer's best soils, it is recommended to seed to a plant population (when using varieties that do not tend to lodge) of about 35 plants/ft<sup>2</sup>. For varieties that tend to lodge, aim for a plant population of 28 plants/ft<sup>2</sup>. For late planted fields it may be necessary to increase the planting rate. Currently, spring wheat varieties with good lodging resistance include Brick, Select, Briggs, Granger, and Traverse. Sampson has been rated as very good. Winter wheat varieties with excellent lodging resistance include Wendy (white), Wesley, and Art. Alice, Camelot, and Millennium are rated as good, and Expedition, Lyman, and Arapahoe are rated as fair.

[http://pubstorage.sdstate.edu/agbio\\_publications/articles/ec774-11.pdf](http://pubstorage.sdstate.edu/agbio_publications/articles/ec774-11.pdf)

The recommended planting rate is dependent upon seed size and germination rate. If the seed kernel size and test weight yield about 16,000 seeds/lb, and if 90% of seeds become viable plants, this will require about 1.8 bu of wheat seed/acre. Wheat yield is determined by the number of kernels per pound of grain, kernels per head and heads per square foot. Wheat kernel counts can vary from fewer than 10,000 to over 20,000 kernels per pound due to kernel size and test weight. Kernels per head can vary widely as well.

A key to high wheat yields is to produce a high population of large heads and maximize the grain fill period. Secondary tillers are smaller and flower later than the main stem. The yield from tillers is less than the yield from the main stem because of a shorter grain fill period and smaller seed size. Producers can somewhat control the number of tillers per plant by adjusting the seeding rate. Higher plant populations will minimize tillering.

### **Seed treatment**

Fungicide seed treatment is a practice that is considered good insurance against a variety of seed and soil-borne diseases that can decrease yield (Hall et al. 2011). Longer and more diverse rotations help to minimize soil-borne diseases, but do not affect seed borne diseases. Seed treatment is a necessity when pursuing high yields.

### **Fertilizers**

To maximize yields, nutrient deficiencies must be minimized. As a rule of thumb, a bushel of wheat contains (thus, removes from the field) 1.5 lb of N, 0.6 lb  $P_2O_5$  and 0.34 lb of  $K_2O$  (Clay et al. 2011). Consequently, a 100-bu/acre wheat crop removes 150 lb/acre of N, 60 lb  $P_2O_5$  and 34 lb/acre of  $K_2O$  (Chapter 12, Clay et al. 2011). To maintain yields, nutrients removed in the harvested crop need to be replaced.

For N management, there are at least three critical times, seeding, V5-stem elongation/jointing, and preheading (Table 1.2). Splitting the N application between planting and post planting has proven very effective. The amount of N that should be applied preplant should range from 40 to 60% of the total N required to reach optimum yield (Total N, fertilizer + credits =  $2.5 \times 100 \text{ bu/a} = 250 \text{ lbs/acre}$ ; Chapter 8).

**Table 1.2. Critical times for N management in wheat.**

1. Seeding.
2. V5-stem elongation or jointing.
3. Preheading.

If the soil contains above average soil test N ( $NO_3-N$ ), the percentage of preplant N can be lower than a soil that is short of soil test N. The purposes of splitting the N are to reduce tillering, reduce the potential for lodging, and to increase

the number of kernels per head. Timing is important as applying the N too early will lead to excessive tillering and disease problems.

The date and amount contained in the second application depends on the wheat type (spring or winter wheat), the rainfall potential, and the soil moisture content. For winter wheat, the second application should be applied prior to stem elongation or jointing (Zadoks 31), whereas for spring wheat the N should be applied around the 5th leaf stage (Zadoks 14-16).

For this N to be utilized by the plant, rainfall is needed to move it into the soil, and, therefore, delaying the application runs the risk that it will not be available to the plant. Conversely, applying nitrogen too early will lead to excessive tillering, increased susceptibility to foliar diseases, delayed flowering (shortening the grain fill period) and lodging. There are

also nitrogen fertilizer products that exhibit slow release properties that may be useful in delaying the nitrogen availability to when the plant needs it. Many fertilizer manufacturers recommend blending slow release fertilizer with conventional fertilizer.

Mid-row banding of nitrogen is another method of delaying nitrogen availability to the plant. Nitrogen availability is delayed because the roots need to grow to reach the band. High wheat yields are often associated with low protein because plant nitrogen is diluted over so many bushels. Additional nitrogen (typically ~30 lb/acre) applied after the boot stage results in low to no yield increase, but typically is effective in producing higher protein content.

Phosphorus and sulfur are critical for early season growth and root development (Chapter 13). Use a starter formulation with the seed of 15 lbs actual  $P_2O_5$ /acre and 15 lb S/acre (as an example, use 33 lb DAP 18-46-0 and 63 lb of ammonium sulfate 21-0-0-24 per acre, which is about 19 lb of N).

### ***Soil organisms***

Earthworms, bacteria, and fungi can help recycle nutrients from one crop to the next (Chapter 17). Each of these organisms provides different contributions to the overall soil health. Earthworms create channels that improve water infiltration. Soil bacteria help decompose crop residues and reduce the residual effects of pesticides, while mycorrhizal fungi increase the effective length of the crop roots, which increases the ability of plants to utilize water and nutrients. Earthworms and fungi are very sensitive to management.

Mycorrhizal fungi populations, which are important in the transfer of some nutrients to plant roots, have been found to be influenced by crop rotation, residue management and tillage. Intensive tillage, fertilizers and short rotations suppress the population of some beneficial soil organisms. A variety of seed treatments and fertilizer additives are available and promoted by different companies. Let the buyer beware, as some of these commercial products have increased yield and some have not. Producers should consult research and evaluate these products to determine if they will result in enough yield increase to pay for themselves.

### ***Weed and insect pest management***

Frequent scouting allows for timely action to manage weed and insect pests within the crop safety window. All treatments should be based on economic thresholds. A healthy crop can tolerate some pest pressure. Additional information on weed management is available in chapters 24, 25, and 26.

### ***Foliar disease control***

High yielding wheat requires healthy plants. Plant health is achieved through a combination of crop rotation, clean seed, balanced fertility, planting disease resistant seed, and responsible use of chemical fungicides. A “yield bump” has often been experienced when applications of strobilurin and/or triazole fungicide products take place at the flag leaf emergence, Feekes 8. Most producers of high yielding wheat use a Feekes 8 application of a product such as Folicur® because of a typical yield bump and its low cost (chemical cost only of ~\$5/acre).

Additional yield bumps have been seen particularly in spring wheat with the application of triazoles at flowering, or Feekes 10.5. This practice should be driven by intense disease scouting and/or if weather conditions indicate a high probability of infection. On-farm research is encouraged to substantiate the value or lack of value of intense fungicide management. It should be noted that widespread use of any pesticide can contribute to resistance to the product.



## Harvest management

Once you have provided the management and inputs necessary to produce high yielding wheat, the final goal is to bring it home. The operation and setup of harvest equipment is critical for minimizing yield losses (Chapter 28). High yielding wheat will lead to much lower harvest speeds.

In some situations it may be desirable to accelerate the drying of wheat. This can be accomplished by windrowing after physiological maturity. The goals of windrowing wheat are to speed up the drying process, reduce shattering losses, and increase test weights (Chapter 27). Grain should be harvested at, or dried quickly to, a suitable moisture content: 14% for short-term storage (less than 6 months) and 13% for long-term storage. Considering the large number of acres farmed by today's producers, a pre-harvest application of a chemical desiccant at physiological maturity can be used in lieu of windrowing, with essentially the same result. Be sure to follow label directions and reference Moeching and Deneke (2009). <http://www.sdstate.edu/sdces/store/Publications/index.cfm?typeVal=2&taxonomy=#taxonomy=&keywords=fs 953&typeVal=2&typeOfPubValue=3>

Producers may also consider harvesting at higher moisture contents (up to 16 to 18%) than is suitable for storage and then drying the grain (at \$2/gal for propane, energy-only drying cost is approximately \$0.06/bu per point). Producers considering windrowing or a pre-harvest application of a chemical desiccant should be aware that either practice initiated before physiological maturity has an adverse effect on grain maturation and can cause shrunken and light kernels.

Following these guidelines will help producers achieve greater profitability and long-term sustainability. Both of these are important to the future of South Dakota farmers and the wheat industry.

### Additional information and references

Beck, D.L., D.E. Clay, and K.D. Reitsma. 2009. Tillage, crop rotations, and cover crops. In Clay, D.E., K.D. Reitsma, and S.A. Clay (eds). *Best Management Practices for Corn Production in South Dakota*. EC929. South Dakota State University, SDSU Extension, Brookings, SD.  
Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/EC929.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC929.pdf)

Carr, P.M., G.B. Martin, and B.A. Melchior. 2005. Adding value to field peas: Understanding rotational effects. Annual report. Dickinson Research Extension Center. Dickinson, ND.  
Available at <http://www.ag.ndsu.nodak.edu/dickinson/research/2004/agron04b.htm>

Clay, D.E., S.A. Clay, C.G. Carlson, and S. Murrell. 2010. *Mathematics and Calculations for Agronomists and Soil Scientists*. International Plant Nutrition Institute. Available at <http://ppi-store.stores.yahoo.net/maandcaforag.html>.

Clay, D.E., K.D. Reitsma, and S.A. Clay (eds). 2009. *Best Management Practices for Corn Production in South Dakota*. EC929. South Dakota State University, SDSU Extension, Brookings, SD.  
Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/EC929.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC929.pdf)

Hall, R.G., J. Rickertswan, K.K. Kirby, J. Hall, and B. Swan. 2011. *Small grains: 2010 South Dakota test results, variety traits, and yield averages*. EC774. South Dakota State University, SDSU Extension, Brookings, SD.  
Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/EC774-11.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC774-11.pdf)

Moeching, M., and A. Deneke. 2009. Harvest aids weed control in small grains. FS953. South Dakota State University, SDSU Extension, Brookings, SD.  
Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/FS953.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/FS953.pdf)

### Acknowledgements

Support was provided by the SD SARE for this chapter. Special thanks to Gary Lemme for editorial suggestions.

---

Fanning, B., and B. Ferguson. 2012. Sustainable production of 100-bushel wheat. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.





## CHAPTER TWO

# Wheat Classes, History, and Breeding Timelines

*Randy L. Englund* ([renglund@midco.net](mailto:renglund@midco.net))

The purpose of this chapter is to provide an overview of wheat history, wheat quality, and classes. There are six major classes of wheat produced in the United States. Each class is uniquely suited for different wheat products and environmental conditions. Environmental factors including rainfall, temperatures, soils, available nutrients and topography influence can cause a wide variety of wheat quality characteristics. Genetics is also a major factor.

Wheat breeding programs take all of these factors into consideration when developing varieties for each region. The wheat protein content has a direct impact on its sustainability for the end use of the grain. Hard and spring wheat generally have a higher protein than soft and winter wheat. Although wheat is planted and harvested somewhere in the world almost every day, the United States has the resources and infrastructure to provide its citizens and the world with the most abundant, reliable and safest supply of wheat.

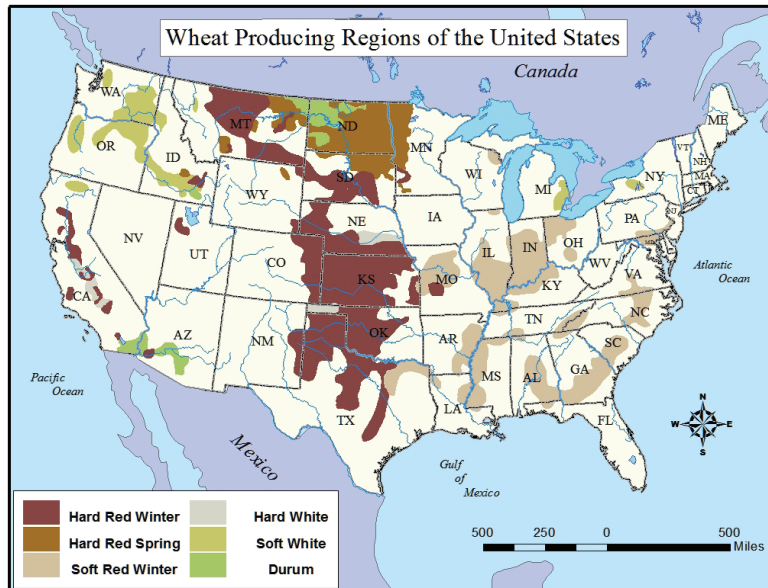
From wheat to flour, the conscientious efforts of wheat producers working with scientists, researchers and technicians provide the world with an economical, plentiful and nutritious food.

### *History of wheat*

<http://www.allaboutwheat.info/history.html>

Wheat has played a prominent role throughout world history and has impacted human development in Europe, Africa, and Asia. It is noted in ancient Chinese writings (2,700 years BC), referenced in the Bible (the Lord's Prayer), grown in the Nile Valley 5000 years ago, and noted by the philosopher Socrates. Back then, as it is today, bread was and is a primary food staple for much of the world's population.





**Figure 2.1. Major growing areas of wheat in the United States.** (Map created by SDSU.)

Wars have been fought and lost over wheat. Napoleon could not feed his troops when they advanced faster than the supply wagons. Even in the United States, the Civil War has been described as a victory of bread over cotton. The North had cereal grains to feed their troops and to trade with Europe whereas the South's major crop was non-edible cotton. President Hoover is quoted as saying, "The first word in war is spoken by guns, the last word has always been spoken by bread." It's no surprise, then, that the availability of this grain directly impacts the success or failure of political leaders.

In North America wheat was grown in the Spanish Missions in the West as well as the coastal areas of Massachusetts in 1602. More recently, it was a critical food during the settlement of the Great Plains. Wheat as an important food source derives its importance from its ability to adapt to new climatic conditions and market requirements.

One of the most important crops for semi-arid areas of the world is wheat. Currently, it occupies 17% of all crop area and tops trade value among all crops. Together with rice and maize, wheat provides >60% of the calories and proteins for our daily life. Therefore, wheat plays a paramount role in world food security.

### ***Species of wheat***

Bread, club, and durum wheat make up 90% of the wheat grown today. The most common species of wheat grown in the world are:

1. Common or Bread wheat (*T. aestivum*, subsp. *aestivum*), the most widely cultivated hexaploid group in the world.
2. Club Wheat (*T. aestivum* subspecies *compactum*).
3. Durum (*T. durum*), a tetraploid form that is the second most widely cultivated wheat.
4. Einkorn (*T. monococcum*), a diploid species with wild and cultivated variants.
5. Emmer (*T. dicoccum*), a tetraploid species, which has been cultivated since ancient times.
6. Spelt (*T. spelta*), a hexaploid species cultivated in limited quantities.

The 200-plus wheat varieties grown in the U.S. are divided into classes according to their growth habits, kernel color, and texture of the ripened grain. Growth habits refer to when they are planted (winter or spring), color refers to the color of the grain (red to white), and texture refers to their hardness or softness.

### ***Wheat classes***

In the United States, six distinct classes of wheat are produced (Fig. 2.1). Each class has characteristics that make it uniquely suited for a given product. These classes include:

1. **Hard Red Winter Wheat** is produced in the Great Plains states in an area extending from the Mississippi River west to the Rocky Mountains, and from Canada to Mexico (Fig. 2.2). Winter wheat is planted in the fall and completes its life cycle in the spring. This class produces flour with a wide range of protein content and has good milling and baking characteristics. This class is used to produce yeast breads and hard rolls.



**Figure 2.2.** Hard red winter wheat.

[http://www.millersgrainhouse.com/bulk/index.php?main\\_page=product\\_info&products\\_id=127](http://www.millersgrainhouse.com/bulk/index.php?main_page=product_info&products_id=127)

2. **Hard Red Spring Wheat** (Fig. 2.3) is used for yeast breads and hard rolls and blending with lesser protein wheat. Hard red spring wheat is generally grown in areas that are too cold for winter wheat. South Dakota farmers predominantly grow hard red winter wheat and hard red spring.



**Figure 2.3.** Hard red spring wheat.

[http://www.ncwheatmontanacoop.com/order/wheat-c-1\\_66\\_35.html](http://www.ncwheatmontanacoop.com/order/wheat-c-1_66_35.html)

3. **Soft Red Winter Wheat** is primarily grown east of the Mississippi River. Soft red winter wheat (Fig. 2.4) is generally high yielding and produces flour with relatively low protein content, which is used to produce flat breads, cereals, cakes, pastries and crackers.



**Figure 2.4.** Soft red winter wheat.

[http://www.uky.edu/Ag/Wheat/wheat\\_breeding/uk\\_wheatbreeding.htm](http://www.uky.edu/Ag/Wheat/wheat_breeding/uk_wheatbreeding.htm)

4. **Soft White Wheat** is primarily grown in the Pacific Northwest and to a lesser extent in California, Michigan, Wisconsin, and New York. Soft White is used for flat breads, cakes, pastries and crackers. Soft white wheat is shown in Figure 2.5.



**Figure 2.5.** Soft white wheat.

<http://www.purcellmountainfarms.com/Organic%20Soft%20White%20Wheat%20Berries.htm>

5. **Hard White Wheat** (Fig. 2.6) is the newest class of wheat and can be grown in many Great Plains states. This class is closely related to red wheat. Hard White is often sweeter than red wheat and is used for yeast breads, hard rolls, noodles, and tortillas.



**Figure 2.6.** Hard white wheat.

<http://www.purcellmountainfarms.com/organic%20hard%20white%20wheat%20berries.htm>  
(htm)

6. **Durum wheat** (Fig. 2.7) is grown in the same northern states that produce hard red spring wheat. This wheat is the hardest of all classes. This wheat is used to make high quality pasta.



**Figure 2.7.** Durum wheat.

<http://www.purcellmountainfarms.com/organic%20hard%20white%20wheat%20berries.htm>

### ***Breeding timeline***

A good breeding program must take all aspects of wheat quality (e.g., yield, climatic tolerance, disease and pest resistance, protein quantity and quality, and baking performance) into account to develop truly superior wheat varieties for use by South Dakota farmers. The process of creating a new variety takes several years. Germplasm of individual plants of known varieties with desirable traits are first selected. They are then crossed, and the progeny are grown through several generations under controlled conditions to produce enough seed for evaluation.

Evaluations are first performed on a small scale in a laboratory to identify any improvements. Varieties exhibiting desirable characteristics in the laboratory are then grown in test plots under normal growing conditions. Wheat varieties from the test plots are evaluated for growth characteristics (e.g., yield and disease resistance), milling and baking quality. Those exhibiting superior characteristics in field tests are released to wheat farmers for commodity production.

Adoption of new varieties by wheat producers can take several years. Because the process of developing, testing, and releasing new wheat varieties is time-consuming, the percentages of each variety grown in a given area change slowly from year to year. It may take an improved variety five years or more to move through initial development to acceptance as a commercial variety for production.

To be effective, a wheat breeding program requires a long-term commitment both in time and funding. The typical time requirement for release of a wheat variety is 10 to 12 years. A wheat breeding program must continuously maintain a germplasm base so that production problems or economic opportunities can be addressed in a timely manner.

### ***A generalized timeline for SDSU plant breeding and variety development programs***

Today, wheat genetic improvement has been using classical and molecular approaches. In classical plant breeding, interbreeding of related plants are used to produce new crop varieties with desirable properties. An example of classical breeding was conducted by Norman Borlaug when semi-dwarf disease resistant varieties were produced. Molecular approaches are being used to speed up classical breeding (Chapter 31).

Breeding can be separated into:

1. *Germplasm acquisition and development.*  
This component occurs continuously and provides the genes for future varieties.
2. *Segregation.*  
This step takes 5 to 6 years and is used to select potential future varieties for their ability to solve specific problems.
3. *Evaluation and testing of advanced lines.*  
Evaluation and testing takes 2 to 4 years during which advanced lines are rigorously tested. Yields and effectiveness of the line may be compared with commercially available varieties through crop testing.
4. *Breeder seed increase.*  
If a potential future variety has promise, a seed increase is conducted. These increases can occur in winter nurseries around the world.
5. *Variety release and commercialization.*  
If the potential variety meets specific goals, an application is submitted to the SDAES variety release committee. If approved, the appropriate paper work must be completed and foundation seed must be produced.
6. *Certified seed.*  
Foundation seed is provided to the seed growers of the SD Crop Improvement Association to produce registered class seed. Certified seed growers produce seed that can be sold to farmers.
7. *Seed assessment.*  
The variety is continuously assessed for its ability to meet production goals. This assessment is based on findings from the crop performance testing, producer and end-user feedback, and sales of certified seed.

#### **Additional information and references**

Ranson, J.K., W.A. Berzonsky, and B.K. Sorenson. 2006. *Hard white wheat. A-1310. NDSU Extension Service, North Dakota State University, Fargo, ND.*  
Available at <http://www.ndvwheat.com/uploads/resources/568/hardwhitewheatbrochure.pdf>

Yakowicz, Susie. 2010. *From durum to stone ground: a primer on wheat classes and flours.*  
Available at <http://www.suite101.com/content/from-durum-to-stone-ground-a-primer-on-wheat-classes-and-flours-a258181#ixzz13OwsVS7K>

*Wheat to Flour, the Story of Man in a Grain of Wheat. Wheat Flour Institute. 1977.*

#### **Acknowledgements**

Support provided by the South Dakota Wheat Commission.

---

Englund R.L. 2012. Wheat classes, history, and breeding timelines. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds.) *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.





## CHAPTER THREE

# Winter and Spring Wheat Growth Stages

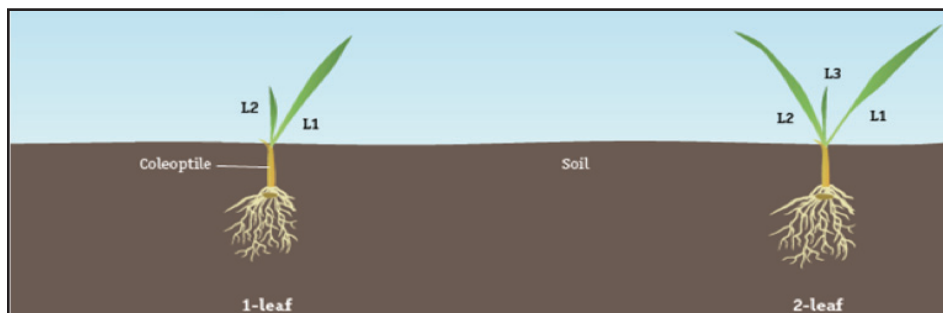
Robert G. Hall ([Robert.Hall@sdsu.edu](mailto:Robert.Hall@sdsu.edu))

Thandiwe Nleya ([Thandiwe.Nleya@sdsu.edu](mailto:Thandiwe.Nleya@sdsu.edu))

The ability to correctly identify the various wheat growth stages is crucial for comparing studies and assessing management options. Many agricultural management products have labels that are based on growth stages. This chapter discusses growth stages according to the Zadoks (prefix Z) and Feekes (prefix F) systems as well as critical management questions at those growth stages.

### Early growth stages

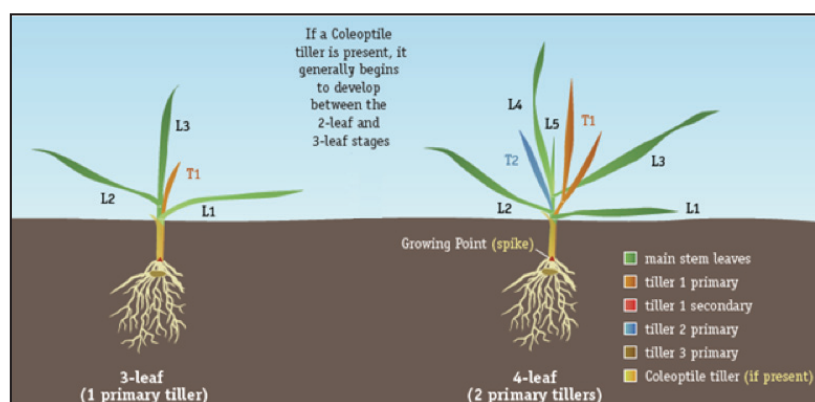
The early season growth of wheat is depicted in Figure 3.1. During these early growth stages, agronomists discuss growth and development in terms of leaves. The development of winter and spring wheat is comparable except the early development of winter wheat occurs in the autumn, while in spring wheat development occurs during early spring. Generally, the length of a given early growth season stage is shorter in spring wheat than in winter wheat. The wheat leaf stages are described below.



**Figure 3.1.**  
The earliest  
stages of  
wheat growth.  
(Source: SDSU)

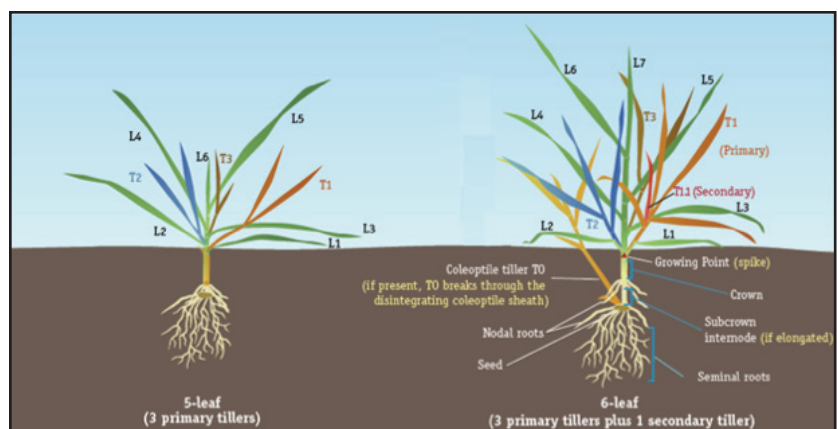


1. *Early development*—begins with the seed imbibing water, swelling, and the elongation of the radicle or root, the seminal roots, and the main shoot enclosed within a shoot sheath or coleoptile. As the coleoptile breaks the soil surface, it ceases growth. Typically, the coleoptile can grow from 2 to 4 inches in length. Planting seeds deeper than the length of their coleoptiles can grow often leads to significant stand reductions at emergence.
2. *One-leaf stage*—shortly after the coleoptile breaks the soil surface, the first leaf (L1), at stages Z10 or F1 appears and continues elongating until its leaf collar is visible (1-leaf stage). A leaf is **not counted until its leaf collar is visible**. By this time the second leaf (L2) at stages Z12 or F1.2 is partially emerged.
3. *Two-leaf stage*—the second leaf elongates until its leaf collar is visible (2-leaf stage). The third leaf (L3) at stages Z14 or F1.3 is partially emerged.
4. *Third-leaf stage*—the third leaf (L3) elongates until its leaf collar is visible (3-leaf stage). During L3 elongation, the first primary tiller (T1) elongates and appears in the axis between L1 and the main stem (L2 and L3). It is between the 2- and 3-leaf stages that some wheat plants can develop differently. At this time, a tiller, called the coleoptile tiller, or T0, can develop in the axis between the coleoptile and main stem shoot (L1, L2, and L3). A fully developed T0 tiller is shown in Figure 3.3. The T0 tiller at stages Z20 or F2 is enclosed within the coleoptile sheath, and will eventually appear above the ground by the 6-leaf stage. The fourth leaf (L4) is partially emerged.



**Figure 3.2. Wheat growth stages through the fourth leaf.** (Source: SDSU)

5. *Fourth-leaf stage*—the fourth leaf elongates until its leaf collar is visible (4-leaf stage). During L4 elongation, a second tiller (T2) appears in the axis between L2 and the main shoot (elongating L3). The fifth leaf (L5) at stages Z22 or F2.2 is partially emerged.
6. *Fifth-leaf stage*—the fifth leaf elongates until its leaf collar is visible (5-leaf stage). During L5 elongation, the third tiller (T3) at stages Z23 or F2.3 appears in the axis between L3 and the main shoot (L4, L5, and the elongating L6). The sixth leaf (L6) is partially emerged.
7. *Sixth-leaf stage*—by the 6-leaf stage a number of changes have occurred (Fig.3.3). The sixth-leaf has elongated and its leaf collar is visible. A secondary tiller (T1.1) appears in the axis between the lowest leaf and next higher leaf on the T1 primary tiller shoot.



**Figure 3.3. Wheat growth stages through the sixth leaf.** (Source: SDSU)

Any T0 tiller initiated at Step 4, will grow, elongate, break through the coleoptile sheath, which has ceased growth, and eventually emerge above ground. The occurrence of T0 tillers is relatively low in wheat. Coleoptile tillers may develop to a small extent in spring, but more so in winter wheat. Recently, there has been an increased interest in breeding winter wheat plants with a higher occurrence of T0 development in their germplasm. Some researchers believe T0 tillers enhance the ability of the plant to increase yield and/or compensate for yield losses due to poor stands or winterkill.

Another feature that is depicted at the 6-leaf stage is an elongated sub-crown internode (SCI). In some wheat seedlings, the SCI elongates while in other seedlings it does not. In cases where a T0 tiller is present, elongation of the SCI will elevate the crown area above the seminal roots and T0 tiller (Fig. 3.1). However, if the SCI does not elongate, the crown area remains immediately adjacent to the T0 tiller (if present) and/or seminal roots where they are bunched together.

### ***Systematic notation of spring wheat growth stages***

This growth and development guide is shown in Table 3.1 and Table 3.2. Two accepted systems of growth stage definition (Zadoks and Feekes) are listed side by side. This chart format is intended to illustrate and discuss the various stages that a spring wheat and a winter wheat plant will accomplish in a typical Dakotas and Minnesota growing season. Tables 3.1 and 3.2 use both the Zadoks and Feekes systems as outlined in the Minnesota Extension publication, *Growth and Development Guide for Spring Wheat*, (Simmons et al. 1995). These plant staging systems are commonly used in wheat. Neither system is decidedly better than the other, but depending on growth stage, one might be better than the other. For example, the Zadoks system is more detailed from germination through the boot stage and from the milk stage through the late hard dough stage or physiological maturity, while the Feekes system is more detailed from head emergence through the flowering stages.

In addition, South Dakota historical climate data is given. Included in the charts is the average number of days and the range in days to a given growth stage after seed germination. Also noted in the charts are the average calendar date and range in calendar dates when 50% of the state spring wheat crop has attained a given growth stage. The general growth and development facts and management suggestions are listed by growth stage. The numerical information is not exact, and variables like the number leaves, nodes, and days may vary slightly.



**Table 3.1. Spring wheat management guide – Zadoks and Feekes stage descriptions, days after emergence, and date that is 50% of the state crop acreage has reached a given stage.**

Growth stage <sup>1</sup>			1,3 Days after Z10	50% Date <sup>2</sup>	General Growth and Development Facts	Management Suggestions
Code		Description				
Zadoks	Feekes					
0		<b>Germination</b>  Dry kernel. Kernel absorbs H <sub>2</sub> O. Radicle emerged. Coleoptile emerged. 1 <sup>st</sup> leaf at coleoptile tip.		<b>Acres Seeded</b>  <i>Range:</i> Apr 14 to Apr 23  <i>Avg.:</i> Apr 22	H <sub>2</sub> O, O <sub>2</sub> , and minimal soil temperatures of 34 to 36 °F are required.  The environment from planting through jointing significantly affects the number of plants/ft <sup>2</sup> .  Emergence – 6 to 8 d.	Use high quality seed. Plant as soil temperatures near 35 °F.  Timely seeding by April 21 helps kernels to develop and fill before high July temperatures reduce yield and test weight.
1	1	<b>Seedling development</b>  1 <sup>st</sup> leaf through coleoptile. 1 <sup>st</sup> leaf unfolded. 2 <sup>nd</sup> leaf unfolded. 3 <sup>rd</sup> leaf unfolded. 4 <sup>th</sup> leaf unfolded. 5 <sup>th</sup> leaf unfolded. 9 <sup>th</sup> leaf unfolded. * 2nd number= no. leaves 50-100% emerged.	<b>0</b> 7/6-8 14/11-16 19/16-22 24/21-28 29/25-33		Early maturity varieties produce 7 while late varieties produce 9 leaves. A new leaf emerges every 3-5 d.  1 <sup>st</sup> tiller appears as the 4 <sup>th</sup> leaf elongates.  The crown and seed can be separated by a short sub-crown internode (SCI) in spring wheat; compared to a longer SCI in winter wheat.	Semi-dwarf varieties have little if any SCI—seed them 1-2" deep.  Standard varieties may or may not have a SCI—seed them 1-3" deep.  Do not seed less than 1" or more than 3" deep depending on variety type (semi- dwarf or standard).  A seeding rate of at least 1.2 but no more than 1.8 million seeds/acre is suggested.
2	2	<b>Tillering</b>  Main shoot (MS) only. MS +1 tiller visible. MS +2 tillers visible. MS +3 tillers visible. MS +4 tillers visible. MS +5 tillers visible. ** 2nd number = no. visible tillers	19/16-22  29/25-33		The MS + 3-5 tillers develop. Tillers that emerge after Z16 often abort. Cool-wet years may result in one or two additional tillers.  Cool wet weather/high fertility increase tiller numbers while hot dry weather/low fertility reduce them.  The environment from tillering through jointing significantly affects the number of heads/plant.	Seeding rates of 1.2 million seeds/acre, early seeding dates and a 1-3" seeding depth promotes tillering; while higher seeding rates, later seeding dates, and deeper seeding suppress it.  Early-season fungicides, if warranted by disease pressure, are applied around this stage.  Apply seasonal N before jointing (Zadoks 31) for maximum yield response.  Wheat tolerates most herbicides at the tillering stage.

Growth Stage <sup>1</sup>			<sup>1,3</sup> Days after Z10	50% Date <sup>2</sup>	General Growth and Development Facts	Management Suggestions
Code		Description				
Zadoks	Feekes					
3		Stem Elongation or Jointing			Internode elongation begins at the 4th node in a plant with about 9 leaves.	Fungicides, if justified by variety susceptibility or foliar fungal disease pressure, are often applied as the flag leaves fully emerge at Zadoks 39 or Feekes 9.
31	6	1 <sup>st</sup> node detectable.	32/28-36			
32	7	2 <sup>nd</sup> node detectable.				
33		3 <sup>rd</sup> node detectable.				
37	8	Last leaf (flag leaf, FL) just visible.	41/38-44		The internode below the head (peduncle) is a major part of the stem.	Do not apply herbicides after Zadoks 39 or Feekes 9. The developing reproductive organs in the head may be sensitive to herbicides, and if later exposed at flowering, may be injured.
39	9	FL collar just visible.	44/41-47		The environment from jointing through flowering significantly affects the total number of heads/plant.	Read/understand labels if using herbicides from Zadoks 39 to 89.
					Moderate to severe yield loss at 24 ° F for 2 h. <sup>4</sup>	
4		Boot		Boot	The FL is more exposed to hail, frost, and pests.	Because the flag leaf is a major photosynthetic surface and major contributor to yield—1 <sup>st</sup> priority should be given to protecting it and the developing head until the wheat is harvested.
41		FL sheath begins to elongate.		Range: Jun 3 to Jun 13		
43	10	Boot begins to swell.	9/49-53		The FL is a major photosynthetic surface.	
45		Boot swollen, "in boot."		Avg.: Jun 11	The environment from boot through late hard dough affects kernel wt.	
47		FL sheath opens.				
49		First awns visible.			Moderate to severe yield at 28 ° F for 2 h. <sup>4</sup>	
5		Head Emergence		Head fully visible	Head is fully exposed to frost, hail, and pests.	Air temperatures of 25- 28 ° F with good soil moisture and higher temperatures of 30-32 ° F, under water stress, often cause damage.
51	10.1	Top of head just visible.				
53	10.2	25% of head visible.				
55	10.3	50% of head visible.		Range: Jun 14 to Jul 25	Plant attains final height.	Apply protectants if justified. Do not apply Strobilurin fungicides if risk of scab is high.
57	10.4	75% of head visible.				
59	10.5	100% of head visible.	54/49-58	Avg.: Jun 23	Severe yield loss at 30 ° F for 2 h. <sup>4</sup>	
6		Flowering (anthesis)			Single heads take about 4 d. to pollinate.	Apply protectants if justified.
61	10.5.1	Flowering begins (anthers appear) in middle of head.				
65	10.5.2	50% of florets have flowered, flowering is complete at top of head.	60/55-64		Temperatures nearing 30 ° F or lower can cause floret sterility; white awns or white heads, lower stem damage, leaf discoloration and a yield reduction.	Fungicides used to manage <i>Fusarium</i> head blight (scab) are best applied at about Zadoks 61 or Feekes 10.5.1 (flowering begins).
69	10.5.3	All florets have flowered, flowering is complete at base of head.				Do not apply Strobilurin fungicides if head scab risk is high.

Growth Stage <sup>1</sup>			<sup>1,3</sup> Days after Z10	50% Date <sup>2</sup>	General Growth and Development Facts	Management Suggestions
Code		Description				
Zadoks	Feekes					
7		Milk development	69/65-73		Starch and protein content determination starts. Ten to 14 days after flowering protein and starch start to accumulate rapidly.  Moderate to severe yield loss at 28 °F for 2 h. <sup>4</sup>	Nitrogen used to increase grain protein should be applied after flowering and by the early milk stage at Zadoks 73 or slightly after Feekes 10.5.4.
71	10.5.4	Kernel watery ripe.				
73		Early milk.				
75	11.1	Medium milk.				
79		Late milk.				
8		Dough development	75/70-78 79/75-83 84/80-88  89/85-93		Best PM indicator – loss of green color from the head and peduncle.  About 30 d. after anthesis the kernels reach maximum dry weight or PM with a 30 to 40% grain moisture level.  Slight to moderate yield loss at 28 °F for 2 h. <sup>4</sup>	Pre-harvest herbicides may be applied after PM at Zadoks 87–89, or when seed moisture is less than 35%.
83	11.2	Early dough.				
85		Soft dough.				
87		Hard dough.				
89		Head loses green color. Physiological maturity (PM).				
9		Ripening		Ripe  Range: Jul 11 to Jul 29  Avg.: Jul 24		Clean and sanitize long-term storage facilities in order to prevent any incidence or storage disease or insect problems.
91	11.3	Kernel hard, difficult to divide by thumbnail.				
92	11.4	Kernel not dented by thumbnail, is harvest ripe.				
		Harvest		Har-vested  Range: Jul 22 to Aug 7  Avg.: Aug. 5		Combine at about 13% to 14% moisture to avoid post-harvest drying costs  Dry to 12% moisture if storing for 30 days or longer.

<sup>1,3</sup> Days after stage Z10, as reported in references 1 and 3; the bold number is the average date for a given stage and 00-00 is the range.

<sup>2</sup> Date when 50% of the state-crop acreage has attained a given stage as reported in reference 2, 1970-1994.

<sup>4</sup> Information on freeze injury was obtained from reference 4–*Spring freeze injury in Kansas wheat*.

**Table 3.2. Winter wheat management guide – Zadoks and Feekes stage descriptions, days after emergence, and date that is 50% of the state crop acreage has reached a given stage.**

Growth stage <sup>1</sup>		Description	<sup>1,3</sup> Days after Z10	50% Date <sup>2</sup>	General Growth and Development Facts	Management Suggestions
Zadoks	Feekes					
<b>0</b>  01 05 07 09		<b>Germination</b>  Dry kernel. Kernel absorbs H <sub>2</sub> O. Radicle emerged. Coleoptile emerged. 1 <sup>st</sup> leaf at coleoptile tip.		<b>Acres Seeded</b>  <i>Range:</i> Sept 5 to Oct 10  <i>Avg.:</i> Sept 15	The environment from planting through jointing significantly affects the number of plants/ft <sup>2</sup> .  Emergence – 6 to 8 d.	Use high quality seed.  Recommended timely seeding dates of about Sept. 10 in the North, Sept. 15-20 in the Central, and Sept 25 to Oct 10 in the South helps plants develop before severe weather sets in.  Direct seed into standing stubble. Stubble traps snow and insulates young seedlings against cold temperatures reducing risk of winterkill.  If seeding into a fallow field, minimize number of tillage operations.
<b>1</b>  10 <sup>+</sup> 11 12 13 14 15 19	<b>1</b>	<b>Seedling development</b>  1 <sup>st</sup> leaf through coleoptile. 1 <sup>st</sup> leaf unfolded. 2 <sup>nd</sup> leaf unfolded. 3 <sup>rd</sup> leaf unfolded. 4 <sup>th</sup> leaf unfolded. 5 <sup>th</sup> leaf unfolded. 9 <sup>th</sup> leaf unfolded. <i>*2nd number = no. leaves 50-100% emerged.</i>	<b>0</b> 7/6-8 14/11-16 19/16-22 24/21-28 29/25-33	Sept 15 to Oct 7  <i>Avg.:</i> Sept 23	Winter wheat plants survive the winter in the seedling stage. About 4 to 5 weeks of active growth is required for seedlings to be well established before freezing to attain maximum cold tolerance and to provide enough energy reserves for spring growth.  Early maturity varieties produce 11 while late varieties produce 15 leaves. A new leaf emerges every 3-5 d.  1 <sup>st</sup> tiller appears as the 4 <sup>th</sup> leaf elongates.	Don't seed too deep or too shallow. Seed at 1.5 to 2 inches deep in a firm seedbed. Planting winter wheat varieties with short coleoptile deeper than 2" can result in weak seedlings with poor ability to survive winter.  In contrast, some winter wheat varieties with a long coleoptile may be seeded relatively deep, depending on the variety—but no deeper than 2.5".

Growth stage <sup>1</sup>			<sup>1,3</sup> Days after Z10	50% Date <sup>2</sup>	General Growth and Development Facts	Management Suggestions
Code		Description				
Zadoks	Feekes					
2	2	<b>Tillering</b>  Main shoot (MS) only. MS +1 tiller visible. MS +2 tillers visible. MS +3 tillers visible. MS +4 tillers visible. MS +5 tillers visible. <i>** 2nd number = no. visible tillers</i>	<b>19/16-22</b>  <b>29/25-33</b>	Late fall to early spring  Avg.: Oct 5	Cool wet weather/high fertility increase tiller numbers while hot dry weather/low fertility reduce them.  The environment from tillering through jointing significantly affects the number of heads/plant.	A seeding rate of 960,000 seeds/acre or 22 seeds/ft <sup>2</sup> is suggested. Early seeding promotes tillering; Properly managed winter wheat has a tremendous ability to tiller and can compensate for thin stands.  Early-season fungicides, if warranted by disease pressure, are applied around this stage.  Fall nitrogen application may enhance rate of tillering, and potentially number of heads/sq.ft.  Excess N applied at this time can lead to lush vegetative growth, which makes the crop susceptible to winterkill.  Wheat tolerates most herbicides at tillering stage.
3		<b>Stem Elongation or Jointing</b>  1 <sup>st</sup> node detectable. 2 <sup>nd</sup> node detectable. 3 <sup>rd</sup> node detectable. Last leaf (flag leaf, FL) just visible. FL collar just visible.	-----  -----	Apr 10 to Apr 30 Avg.: Apr 20  Apr 20 to May 10 Avg.: May 1	Feekes 6 or Zadoks 31 will not occur prior to vernalization, which is required for spikelet differentiation.  The environment from jointing through flowering significantly affects the total number of heads/plant.	Fungicides, if justified by variety susceptibility or foliar fungal disease pressure, are often applied when flag leaves are fully emerged at Zadoks 39 or Feekes 9.  Do not apply herbicides after Zadoks 39 or Feekes 9. The developing reproductive organs in the head may be sensitive to herbicides, and when later exposed at flowering, may be injured.  <b>Read/understand</b> labels if using herbicides from Zadoks 39 to 89.

Growth Stage <sup>1</sup>			<sup>1,3</sup> Days after Z10	50% Date <sup>2</sup>	General Growth and Development Facts	Management Suggestions
Code		Description				
Zadoks	Feekes					
4	10	Boot		Boot	The FL is more exposed to hail, frost, and pests. The FL is a major photosynthetic surface.  Environmental stress prior to flag leaf emergence can reduce number of spikelets/head.  The environment from boot through late hard dough affects kernel wt.	Because the flag leaf is a major photosynthetic surface and major contributor to yield—1 <sup>st</sup> priority should be given to protecting it and the developing head until the wheat is harvested.
41		FL sheath begins to elongate.		Range: May 5 to May 25		
43		Boot begins to swell.				
45		Boot swollen, "in boot."				
47		FL sheath opens.		Avg.: May15		
49		First awns visible.				
5	10.1 10.2 10.3 10.4 10.5	Head Emergence		Head fully visible	Head is fully exposed to frost, hail, and pests.  Plant attains final height.	
51		Top of head just visible.				
53		25% of head visible.				
55		50% of head visible.		Range: May 27 to June 23		
57		75% of head visible.				
59		100% of head visible.		Avg.: Jun 4		
6	10.5.1 10.5.2 10.5.3	Flowering (anthesis)	60/55-64	July 10 to Aug 10	Single heads take about 4 d. to pollinate.	Apply protectants if justified.  Fungicides used to manage <i>Fusarium</i> head blight (scab) are best applied around Zadoks 61 or Feekes 10.5.1 (flowering begins).  Do not apply Strobilurin fungicides if head scab risk is high.
61		Flowering begins (anthers appear) in middle of head.		Avg.: July 20		
65		50% of florets have flowered, flowering is complete at top of head.				
69		All florets have flowered, flowering is complete at base of head.				

Growth stage <sup>1</sup>			1,3 Days after Z10	50% Date <sup>2</sup>	General Growth and Development Facts	Management Suggestions
Code		Description				
Zadoks	Feekes					
7		Milk development			Starch and protein content determination starts. Ten to 14 days after flowering protein and starch start to accumulate rapidly.	Nitrogen used to increase grain protein should be applied after flowering and by the early milk stage at Zadoks 73 or slightly after Feekes 10.5.4.
71	10.5.4	Kernel watery ripe.	69/65-73		Moderate to severe yield loss at 28 °F for 2 h. <sup>4</sup>	
73		Early milk.				
75	11.1	Medium milk.				
79		Late milk.				
8		Dough development			Best PM indicator– loss of green color from the head and peduncle.	Pre-harvest herbicides may be applied after physiological maturity at Zadoks 87–89, or when seed moisture is less than 35%.
83	11.2	Early dough.	75/70-78	Avg.: July 27	About 30 d. after anthesis the kernels reach maximum dry weight or PM at about 30 to 40% grain moisture.	Grain in hot dry weather will lose 2-3 moisture percentage points per day.
85		Soft dough.	79/75-83			
87		Hard dough, head loses green color.	84/80-88			
89		Physiological maturity (PM).	89/85-93			
9		Ripening			The plant is completely yellow. Kernel has about 20 to 25% grain moisture.	Clean and sanitize long-term storage facilities in order to prevent any incidence or storage disease or insect problems.
91	11.3	Kernel hard, difficult to divide by thumbnail.		Ripe Range: Jul 9 to Aug 7		
92	11.4	Kernel not dented by thumbnail, is harvest ripe.				
		Harvest				
				Harvested Jul 1 to Aug 7		Combine at about 13% – 14% moisture to avoid post-harvest drying costs
				Avg.: Aug. 5		Dry to 12% moisture if storing for 30 days or longer.

<sup>1,3</sup> Days after stage Z10, as reported in references 1 and 3; the bold number is the average date for a given stage and 00-00 is the range.

<sup>2</sup> Date when 50% of the state-crop acreage has attained a given stage as reported in reference 2, 1970-1994.

<sup>4</sup> Information on freeze injury was obtained from reference 4—*Spring freeze injury in Kansas wheat*.

#### **Additional information and references**

Gregoire, T., G. Endres, and R. Zollinger. 2000. *Identifying leaf stage in small grain. W-564 (Revised).* NDSU Extension Service, North Dakota State University, Fargo, ND.

Karow, R.S., E.L. Klepper, R.W. Rickman, and T.R. Toll. 1993. *Early growth and development of cereals. EM 8542.* OSU Extension Service, Oregon State University, Corvallis, OR.

Ranek, J. C. 1995. *Seeding to harvest.* South Dakota Agricultural Statistics Service.

Simmons, S. R., E.A. Oelke, and P. M. Anderson. 1995 (Revised). *Growth and development guide for spring wheat.* University of Minnesota, Minnesota Extension Service Folder AG-FO-2547.

Shoyer, J.P., M.E. Mikesell, and G.M. Paulsen. 1995. *Spring freeze injury to Kansas wheat. C-646.* Agricultural Experiment Station & Cooperative Extension Service, Kansas State University, Manhattan, KS.

#### **Acknowledgements**

Information provided by Larry Osborne (former Extension Plant Pathologist for disease control), Ron Gelderman (Extension Soils for soil fertility management), and Michael Moechnig (Extension Weeds for herbicide management), is gratefully acknowledged.

---

Hall, R.G., and T. Nleya. 2012. Winter and spring wheat growth stages. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production.* South Dakota State University, SDSU Extension, Brookings, SD.







## CHAPTER FOUR

# Winter Wheat Planting Guide

Thandiwe Nleya ([Thandiwe.Nleya@sdstate.edu](mailto:Thandiwe.Nleya@sdstate.edu))

Winter wheat planting in South Dakota begins in mid-September with the aim of establishing a healthy and vigorous plant that can survive winter temperatures (Fig. 4.1). A number of factors, some climatic and others under the direct control of the grower, affect the success of the winter wheat crop. The major concern at planting time is moisture availability for germination and seedling establishment. While planting early may help the soil moisture situation, it increases the risk of disease and insect damage from summer crops. Direct



**Figure 4.1. Wheat plants must be well established with 3-5 leaves and a well-developed crown before freezing.** (Photo credit: C. Stymiest, SDSU)

seeding winter wheat into standing stubble is recommended to reduce the risk of winterkill. If planting winter wheat into a conventional fallow field, it is important to minimize the number of tillage operations immediately before planting. This chapter discusses winter wheat adaptive mechanisms, planting dates, seeding rates, planting depths, variety selection, winterkill and reseeding considerations.

### *Winter wheat characteristics*

The vegetative characteristics of winter wheat and spring wheat are similar with the exception that winter wheat can withstand freezing temperatures for extended periods of time at the seedling phase. Winter wheat also requires a period of exposure to near freezing temperatures (vernalization) to trigger reproductive development. Hard red and white

classes of wheat are available in South Dakota. Both classes generally have good milling and baking qualities.

### ***Vernalization and cold acclimation***

Winter wheat seedlings emerging in the fall are not tolerant to subfreezing temperatures any more than spring wheat. To cope with low temperature stress, winter wheat has evolved adaptive mechanisms that are temperature regulated. These adaptive mechanisms are known as vernalization and cold acclimation.

Cold acclimation, or “hardening,” is required before wheat plants can survive subfreezing temperatures in winter. During vernalization, wheat plants are exposed to near-freezing temperatures (near 40° F is optimum). The acclimation process is induced by the gradual decrease in average temperature during fall to early winter. This involves lowering of moisture content of the crown (area at the base of the shoot), slowing down of the growth process and accumulation of soluble carbohydrates, which helps to resist frost damage.

The soil temperature at crown depth (2 to 3 inches deep) determines the rate of cold hardiness. For winter wheat to fully harden, a temperature below 50° F at the crown depth for 4 to 8 weeks is required. After this exposure, winter wheat will maintain a high level of winter hardiness, provided the temperature at crown level remains below freezing. Generally 8 to 12 weeks of growth under field conditions are required for full development of winter hardiness. During the first 4 to 5 weeks, the temperatures should be above 50° F at crown depth. During this period of time, the plant produces the energy that is stored in the crown to survive winter and to initiate spring growth.

It is important to note that cold acclimation is genetically controlled by variety and that not all winter wheat varieties have the same winter hardiness level. Thus, it is possible to have winterkill in one field planted to a less winter hardy variety and to have a good stand in the next field over.

### ***Management practices for increased winter survival***

Stubble and snow cover during a cold spell can influence the extent of winterkill (Fig. 4.2). Direct seeding winter wheat into stubble or no-till is a recommended crop management practice in central and western South Dakota. Snow trapped by the stubble insulates wheat seedlings against cold temperatures, thereby reducing risk of winterkill. Research conducted in western South Dakota has shown that soil temperature at crown depth under stubble can be 5 to 7 degrees warmer than under conventional fallow; these differences in temperature can influence winter survival of wheat seedlings. Seeding winter wheat into broadleaf crop stubble is recommended to reduce insect, disease and weed problems. Even though seeding into wheat stubble is common, disease risks are associated with this practice.

If planting winter wheat into a conventional fallow field, it is important to minimize the number of tillage operations immediately prior to planting. Plowing, or other deep tillage operations, can reduce seedbed firmness, bury protective residues, and increase the risk of winterkill. Planting into a fallowed field can also leave wheat plants unprotected and more subject to winterkill. Tillage can lead to greater soil water losses, and, if done shortly prior to seeding, soil moisture may be inadequate for rapid and uniform emergence of seedlings.

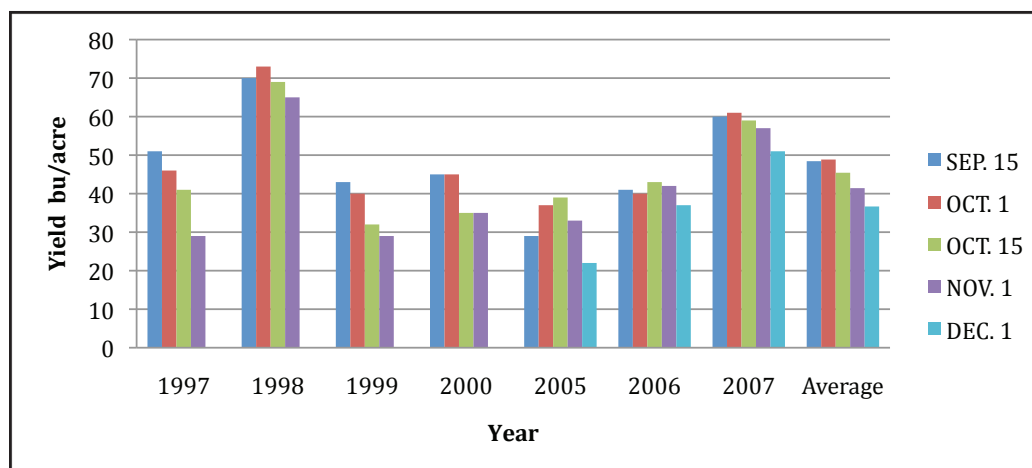
**Figure 4.2. Management techniques to minimize winterkill and improve plant health.**

1. Direct seed into stubble.
2. Minimize tillage operations prior to planting.
3. Plant between September 10 and October 10.
4. Planting early can increase insect and disease problems.



### *Planting date*

The optimal planting window for winter wheat in South Dakota is September 10 through October 10 (Fig. 4.3). Winter wheat germinates in the fall and survives the winter at the seedling stage. Wheat plants should be well established before freezing to attain maximum cold tolerance and to accumulate enough energy reserves for survival and early regrowth in the following spring. Generally, 8 to 12 weeks of growth is needed to condition the plants for the winter.



**Figure 4.3. Winter wheat grain yield as affected by planting date in South Dakota.** Data collected over seven different years and averaged over eight varieties. (Unpublished data of studies conducted in western South Dakota: Nleya, Rickertsen and Swan, 2005-2007; Stymiest, Rickertsen and Swan, 1997-2000)

Planting wheat too early may produce excessive fall growth reducing amounts of soil moisture and nutrients. Early planted wheat may also create a green bridge between wheat crops that serve as alternate hosts for important winter wheat pests. For example, winter wheat seedlings can be infected by barley yellow dwarf virus or wheat streak mosaic virus, which can lead to a significant reduction in yields. Research from western South Dakota has shown that grain yield is decreased and that the crop typically suffers substantial winter injury when planting occurs later than October 15 (Fig. 4.3).

### ***Seeding rates***

An important factor impacting yield is the number of spikes per unit area. Winter wheat should be planted at a rate of 960,000 pure-live-seeds per acre (22 pure-live-seeds per square foot) between September 10 and October 10. When seeding later than the recommended planting window, the rate should be increased. However, properly managed winter wheat has a tremendous ability to tiller and can compensate for thin stands. To determine seeding rate in pounds per acre, a seed count per pound is necessary. Varieties or seed lots with a larger seed size will require higher seeding rates (lbs/acre) to achieve the required plant population (plants/acre). Guidelines accounting for dry soil and late planted seeds are provided in Figure 4.4.

**Figure 4.4. Dry soil and late planting seeding guidelines.**

1. Increase seeding rate to approximately 28 pure-live-seeds per square foot under dry conditions to account for poor seedling germination and seed mortality.
2. Increase seeding rate to approximately 28 pure-live-seeds per square foot when planting later than the recommended planting window.
3. Plant seeds at a depth of 1.5 to 2 inches under optimum conditions.

### ***Seeding depth and seedbed preparation***

Seeding depth can have a large influence on plant establishment, especially under conditions of poor soil moisture. Under optimum conditions, growers should plant winter wheat at a depth of 1½ to 2 inches into a firm seedbed. Planting deeper than two inches delays emergence and can result in weak, spindly seedlings with a reduced ability to survive the winter. Under dry conditions, it may be necessary to plant deeper to place seed into moist soil. Under such conditions, growers should choose a variety with a longer coleoptile. It is also important to pay close attention to soil-to-seed contact under drier conditions. Poor soil cover of the seed can expose the crown and adversely affect winter survival.

### ***Variety selection***

Selecting a winter wheat variety to plant is one of the most important decisions a grower has to make (Chapter 6). When selecting a variety, growers should consider the various variety traits (Fig. 4.5). Winter wheat variety yield trials are conducted yearly by the South Dakota State University Crop Performance Testing program. Results from the trials are available at <http://www.sdstate.edu/ps/extension/crop-mgmt/variety-trials-results.cfm>.

Information for Nebraska, Minnesota, and North Dakota can also be consulted at the following addresses:

Nebraska [http://citnews.unl.edu/winter\\_wheat\\_tool/index.shtml](http://citnews.unl.edu/winter_wheat_tool/index.shtml)

Minnesota <http://www.maes.umn.edu/10varietaltrials/redwinterwheat.pdf>

North Dakota <http://www.ndwheat.com/growers/default.asp?ID=478>

When considering yield, consider yield potential, wheat quality, and yield stability. While high yield is important, varieties that perform consistently under different climatic conditions may be more desirable. When selecting a high-yielding and good-quality variety, try to locate replicated data that summarizes several years and locations. Choose the variety that, on average, performs the best at multiple locations near you over several years. Information on different wheat cultivars is available in Hall et al. (2011).

Winter hardiness is a desirable characteristic. Most of the current winter wheat varieties have improved winter hardiness and are rated from fair to excellent. Regardless of the winter hardiness rating, winterkill can be reduced by seeding into protective cover.

The importance of a trait may depend on a grower's specific production system and farm location. For example, if a certain disease is expected to be a problem in a specific region in a particular year, using a winter wheat variety with resistance traits to that particular disease can minimize yield losses. Early maturing winter wheat varieties may be appropriate for drier environments as they are more likely to escape late season drought. In higher yielding environments, straw strength may be important to prevent the wheat crop from lodging.

Quick and uniform seedling emergence is important to achieve good plant stands. The coleoptile is the leaf sheath that surrounds the first true leaf. The length of the coleoptile is important particularly when planting under dry conditions. Varieties with longer coleoptile length emerge better when planted deep.

The major use of winter wheat grown in South Dakota is in bread making. Winter wheat grain is tested for milling and baking quality to make sure standards for millers and bakers are met. Hard white wheat can also be used for making noodles and tortillas.

**Figure 4.5. Traits that should be considered when selecting a winter wheat variety.**

Yield potential	Winter hardiness
Protein content	Yield stability
Maturity	Baking quality
Test weight	Lodging resistance
Disease and insect resistance	Coleoptile length

### ***Winterkill***

Winterkill can result from inadequate hardening due to late emergence in the fall, or a sudden drop in temperature. Even fully hardened wheat plants can suffer winterkill, if temperatures drop below a crown temperature of 50° F. Injury or death, resulting from cold-induced desiccation, may also occur at temperatures above 50° F if the tissue moisture drops below 55%. In general, the crown is not exposed to killing temperatures if the plant is insulated by snow cover.

In addition, producers should be aware that it is not only the lowest temperature reached that is important in determining the level of winterkill, but also the length of the period of exposure to sub-lethal temperatures. For example, wheat plants exposed to a temperature of 0 degrees F will experience high levels of winterkill after a shorter period of exposure compared to plants exposed to a temperature of 5° F.

### ***Determining the level of winterkill***

Early in the spring, winterkill can be determined using the Bag Test (Fig. 4.6). The Bag Test can be used to provide an early indication of survival. If information is not required immediately, the best way to assess winterkill is to wait until plant growth commences.



**Figure 4.6. The Bag Test for determining winterkill.**

1. Carefully dig wheat plants from different parts of the field with a spade – remove up to three inches of soil containing the plant crown and roots.
2. Thaw the samples at room temperature.
3. Wash with cold water to remove soil from roots.
4. Cut leaves at about 1.5 inches from the crown and roots just below the crown.
5. Rinse crown with clean, cool tap water.
6. Place at least five crowns in a plastic freezer bag; inflate and tie shut.
7. Place bag in a lighted room but not in direct sunlight.
8. After 5–7 days, a healthy crown should show one-half inch or more of new growth.
9. Plants that are not growing after 6 days are assumed to be dead.

### ***Spring freeze injury***

In spring as temperatures warm up, plant growth accelerates and eventually plants lose the ability to tolerate cold stress. If low temperature stress occurs during spring growth, injury from freezing can occur. Factors that influence spring freeze injury include plant growth stage, plant moisture content, duration of exposure, wind and precipitation. Plants at the reproductive stages (late boot to heading) are most sensitive to freeze injury (Table 4.1). At this stage, temperatures slightly below freezing can severely injure wheat, causing considerable yield reduction. The degree of damage to the crop is also influenced by the duration of low temperatures. Prolonged exposure to low temperature causes much more injury than brief exposure to the same temperature.

It is important to know the symptoms of freeze injury and the plant parts that are affected at each growth stage. To evaluate damage, producers need to carefully monitor the crop three to five days after the low temperature event. It is also important to note that cool weather after freezing temperatures may delay the appearance of injury symptoms, thus damage symptoms are not immediately apparent. The symptoms are growth stage dependent and listed as follows:

1. *At tillering stage*, the growing point is just below the soil surface and is protected from injury. Most of the damage will therefore occur to the leaves, which become yellow in color and shows burning at the tips within one to two days after freezing. Injury at this stage will slow growth and reduce total tiller numbers. Growth of new leaves and tillers usually resumes with warmer temperatures and yield reduction may range from slight to moderate.
2. *At jointing stage*, leaves will show similar symptoms as the tillering stage but the most serious injury at this stage occurs to the growing point. Locate the growing point by splitting the stem just above the uppermost node. A normal growing point is bright yellow-green; a damaged growing point is white or brown and water-soaked in appearance.
3. *At the boot stage*, look for injury on the small head which can be found above the top node in the stem. A healthy head should be white or light green. An amber or watery appearance would indicate freeze damage.

4. *At the heading stage*, the most apparent symptom is bleaching (chlorosis) of the awns to a white instead of the normal green color. Other symptoms will be similar to those that occur at earlier stages of growth.
5. *At the flowering (anthesis) stage*, the plant is very sensitive to freezing temperatures. Exposure to freezing at this stage kills male parts of the flower, causing sterility. The anthers are white instead of the normal light green or yellow color.
6. More information on spring freeze injury can be found in the publication, *Spring Freeze Injury to Kansas Wheat*. <http://www.ksre.ksu.edu/library/crpsl2/c646.pdf>

#### ***Economic threshold for reseeding***

Freezing injury or winterkill only affects plants in certain parts of the field, especially depressions or lower areas of the field. West or south facing slopes or hilltops that first lose snow cover also are prone to winterkill. Where main tillers have been damaged, secondary tillers may grow and enhance the stand. Where stands are poor and re-seeding is an option, seed cost, land preparation, and planting costs should be taken into consideration. In some instances it may be better to leave the land fallow and then plant it to winter wheat the following fall.

Depending on seeding rates, optimum plant stands are 20–28 plants per square foot. The general rule is that 50% or more of the optimum stand is adequate. Winter wheat has the ability to tiller to compensate for lower plant densities. When stands are thin or weakened, consider early nitrogen application to encourage tillering and early control of weeds.

<b>Table 4.1. Temperatures, symptoms, and yield impacts from exposure to 2 hours of cool temperature at selected growth stages.</b> (Adapted from Shroyer et al. 1995)			
Growth stage	Temperature causing injury (2 hrs exposure)	Symptoms	Yield impact
Tillering	12° F	Leaf chlorosis; burning leaf tips; silage odor	Slight to moderate
Jointing	24° F	Death of growing point; leaf yellowing or burning; lesions, odor	Moderate to severe
Boot	28° F	Floret sterility; spike trapped in the boot; damage to lower stem; leaf discoloration, odor	Moderate to severe
Heading	30° F	Floret sterility; white awns or spikes; damage to lower stem; leaf discoloration	Severe
Flowering	30° F	Floret sterility; white awns or spikes; damage to lower stem; leaf discoloration	Severe
Milk	28° F	White awns or white spikes; damage to lower stem; leaf discoloration; shrunken; roughened, or discolored kernels	Moderate to severe
Dough	28° F	Shriveled, discolored kernels; poor germination	Slight to moderate



### ***Reseeding options after a winterkill or hail***

Reseeding options for a grain crop include proso millet, grain sorghum and sunflower (Table 4.2). Proso millet requires the least amount of water and produces grain in 80 to 90 days, which would allow winter wheat to be planted the fall after the millet. Grain sorghum and sunflowers would require mid to late summer rains to produce a good crop, and grain sorghum is best suited to elevations of 2500 feet or lower.

Options for forage crops include foxtail millet, sudangrass, sorghum-sudangrass and forage sorghum. In a rotation with fallow it may be more desirable to plant the alternative crop into fallow ground intended for wheat planting in the fall and to utilize the hailed wheat land for fall winter wheat planting. This would avoid problems with the decaying wheat residue interfering with crop growth and residual herbicides applied to the wheat crop injuring the reseeded crop. Latest dates for seeding these crops are given on Table 4.2. Information on seeding rates is available in Hall (2010), *Emergency Late-Seeding Options*.

[http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/exex8120.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/exex8120.pdf)

It is important to cross-reference crops with prior herbicide usage to make sure they are compatible with possible herbicide carryover. Information on small grain herbicide cropping restrictions is available in Moechnig and Deneke (2008), *Replant Restrictions: After Herbicide Applications in Small Grains*.

[http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/exex8157.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/exex8157.pdf)

If the crop is insured, it is important to consult with the crop insurance agents before re-seeding or abandoning the crop (Chapter 9).

### ***Grazing winter wheat***

If producers want to salvage their winter wheat as forage, they have to be aware of a few precautions. Winter wheat can be grazed or harvested as silage; however, haying is difficult due to the long curing time needed to reduce moisture content. Successful small grain grazing requires precautions because:

1. *Grass tetany* (sometimes known as wheat poisoning) associated with imbalances of magnesium and calcium nutrient can occur with older cows, calving cows, or lactating cows.
2. *Bloat*, though not as common as legume-induced bloat, can occur with immature wheat in the leafy stage, particularly in stocker cattle.
3. *Nitrates* can accumulate under drought stress or frost and hail damage.

Nitrate itself is not toxic to animals, but at elevated levels, it can cause a noninfectious disease called nitrite poisoning. All plants contain nitrates, but toxic nitrate levels for livestock are mostly associated with forages. Crops grown under “stress” conditions or on soils that have received high applications of manure or nitrogen fertilizer are suspect.

Usually nitrate levels tend to accumulate in forages immediately after a drought-ending rain. Since peak nitrate plant levels occur in the morning, delay haying or grazing until the afternoon of a sunny day can reduce this risk. Nitrate toxicity is most likely to occur when livestock are pastured or fed green-chop, followed by hay. Silage is the least hazardous feed. Ensiling forage usually lowers the nitrate level by 10 to 60%.

Table 4.2. Latest seeding date for reseeding crops after winterkill. (Hall 2006)	
Crop Type	Latest recommended seeding date
<b>Row Crops</b>	
Corn	June 10
Sorghum for grain	June 30
Soybean	June 25
Sunflower	July 1, July 5 for southern half of the state
<b>Alternative Crops</b>	
Buckwheat	July 10
Foxtail millet	July 5-10
Proso millet	July 5-10
<b>Forage Crops</b>	
Forage sorghum	July 20
Brassica spp	July 15
Sudangrass and Sudan hybrids	July
Sudangrass-Sorghum hybrids	July 1-15
Winter Rye	July 15

It is always a good practice to test for nitrate levels before you graze or feed. Commercial labs have the capacity to test for nitrate. Farmers should collect a representative sample to send to the lab. This could be done by taking 20 stems randomly picked by traversing in a zigzag pattern across an entire field. Clip the plants at ground level. A nitrate test level of less than 1500 ppm (0.15%) is generally safe for all conditions and livestock. For other interpretations of nitrate tests, consult with the Extension livestock specialist.

Also it is important to note that several cereal herbicides have restrictions on crop use for forages. More information is available in Moechnig and Deneke (2006), *Restrictions for Harvesting Small Grain Forages after Herbicide Applications*.

[http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/exex8156.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/exex8156.pdf)

#### Additional information and references

Anderson, J.A., G.L. Linkert, and J.J. Wiersma. 2006. Hard red winter wheat. Minnesota Agricultural Experiment Station, University of Minnesota. Available at <http://www.maes.umn.edu/06VarietalTrials/winterwheat.pdf>

Fowler, D.B. 2002. Winter cereal production. Crop Development Centre, University of Saskatchewan, Saskatoon, SK, Canada. Available at [http://www.usask.ca/agriculture/plantsci/winter\\_cereals/](http://www.usask.ca/agriculture/plantsci/winter_cereals/)

Hall, R.G. 2010. Emergency late-seeding options. ExEx8120. South Dakota State University, SDSU Extension, Brookings, SD. Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/exex8120.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/exex8120.pdf)

Hall, R.G., J. Rickertsen, K.K. Kirby, J. Hall, and B. Swan. 2011. Small grains: 2010 South Dakota test results, variety traits, and yield averages. EC774-11. South Dakota State University, SDSU Extension, Brookings, SD. Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/EC774-11.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC774-11.pdf)

Klein, R.N., D.J. Lyon, D.D. Baltensperger and L.A. Nelson. 2005. Using winter wheat yield data to improve variety selection. EC197. University of Nebraska-Lincoln Extension, Lincoln, NE. Available at [Elkhorn.unl.edu/public/live/ec197/build/ec197.pdf](http://Elkhorn.unl.edu/public/live/ec197/build/ec197.pdf)

Moechnig, M., and D. Deneke. 2006. Restrictions for harvesting small grain forages after herbicide applications. ExEx8156. South Dakota State University, SDSU Extension, Brookings, SD. Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/exex8156.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/exex8156.pdf)

Moechnig, M., and D. Deneke. 2008. Replant restrictions: After herbicide applications in small grains. ExEx8157. South Dakota State University, SDSU Extension, Brookings, SD. Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/exex8157.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/exex8157.pdf)

Rickertsen, J.R., T. Nleya, W. Berzonsky and L. Osborne. 2010. (revised annually). 2010 Winter wheat variety yield results and planting tips. ExEx8136. South Dakota State University, SDSU Extension, Brookings, SD. Available at <http://www.sdstate.edu/ps/pubs/upload/ExEx8136.pdf>

Shroyer, J.P., M.E. Mikesell, and G.M. Paulsen. March 1995. Spring freeze injury to Kansas wheat. C646. Agricultural Experiment Station and Cooperative Extension Service, Kansas State University, Manhattan, KS. Available at <http://www.ksre.ksu.edu/library/crpsl2/c646.pdf>

Wiersma, J.J., B.R. Durgan, C. Hollingsworth, I.V. MacRae, and G. Rehm. 2006 Winter wheat in Minnesota. MI-08421. University of Minnesota Extension. Available at <http://www.extension.umn.edu/distribution/cropsystems/DC8421.html>

#### Acknowledgements

Support for this chapter was provided by South Dakota State University, SDSU Extension, South Dakota Experiment Station, USDA-AFRI, NCR-SARE, South Dakota Wheat Commission and South Dakota Oilseed Council.

---

Nleya, T. 2012. Winter wheat planting guide. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). iGrow Wheat: Best Management Practices for Wheat Production. South Dakota State University, SDSU Extension, Brookings, SD.



## CHAPTER FIVE

# Spring Wheat Planting Guide

Robert G. Hall ([Robert.Hall@sdstate.edu](mailto:Robert.Hall@sdstate.edu))

The first step in maximizing profitability is selecting the best cultivar and planting at the appropriate rate, date, and time. The purpose of this chapter is to provide spring wheat planting guidelines.

### Planting Rules of Thumb

- Beat the heat.
- Plant by the 3rd week in April.
- Calibrate the planter and check planter accuracy.
- Use high quality seed.

### Seeding dates

Suggested and historical spring wheat seeding dates for the different regions in South Dakota are provided in Table 5.1. Seeding dates listed in the “Desired range” column are our best estimate.

A spring wheat planting date rule of thumb is to “beat the heat.” Wheat is a cool-season crop that does best under moderate, as opposed to high temperatures. Generally, the use of relatively early maturing varieties that are seeded in the desired range will generate the best opportunity for a good crop. The selection of early maturing varieties that are planted in April will enable the bulk of the crop to be produced before the high temperatures typically observed between mid-July to mid-August.

To beat the heat, spring wheat planting should be seeded during the first three weeks of April. If the soil temperatures permit (34-36° F), and if the 30-day forecast is favorable (temperatures greater than freezing), consider planting earlier. Planting after May 10 is not recommended because average or higher temperatures can reduce yields and quality. However, if temperatures are cooler than average, planting after May 10 can produce a “good” crop.

**Table 5.1. Suggested and historical spring wheat seeding dates for the 9 South Dakota regions.**

Approximate spring wheat seeding dates by region						
Suggested seeding dates*			Historical acres seeded, 1970 – 94 <sup>1,2</sup>			
Earliest	Latest	Desired range	10%	50%	90%	Reporting District
Apr. 3	May 24	Apr. 8-27	Apr. 10	Apr. 27	May 19	NW
Apr. 2	May 20	Apr. 8-27	Apr. 9	Apr. 26	May 12	NC
Apr. 1	May 20	Apr. 8-27	Apr. 8	Apr. 26	May 15	NE
Apr. 1	May 15	Apr. 5-22	Apr. 1	Apr. 20	May 13	WC
Apr. 1	May 15	Apr. 5-22	Apr. 1	Apr. 20	May 8	C
Apr. 1	May 15	Apr. 5-22	Apr. 1	Apr. 20	May 11	EC
Apr. 1	May 15	Apr. 1-18	Apr. 7	Apr. 24	May 13	SW
Mar. 25	May 10	Mar. 25-Apr. 15	Apr. 1	Apr. 17	May 9	SC
Mar. 25	May 10	Mar. 25-Apr. 10	Apr. 1	Apr. 16	May 11	SE

<sup>1</sup> South Dakota field crops—planting to harvest. 1979. South Dakota Agricultural Statistics Service.  
<sup>2</sup> South Dakota—seeding to harvest. September 1995. South Dakota Agricultural Statistics Service.

Since the 1970s, the better performing South Dakota varieties have been those with a relatively early maturity as opposed to a medium or medium-late maturity rating. Since the 1980s, the release of early maturity varieties along with early planting dates (April 1-21) have led to more consistent yields. In contrast, the use of late maturity varieties has often resulted in less consistent high yields.

### Seeding rates

The recommended seeding rate for spring wheat is approximately 1.2 million seeds per acre, or 28 seeds/ft<sup>2</sup>. This recommendation results in a final stand of about 1 million seedlings per acre or 23 plants/ft<sup>2</sup>. These 1.2 million seeds per acre can be delivered by using the specified PLS/foot-of-row values indicated for a “Firm seedbed” at 28 seeds/ft<sup>2</sup> in Table 5.2a. Should planting occur later, then the PLS/foot-of-row values for a “Late seeding” at 42 seeds/ft<sup>2</sup> is suggested. Seeding rates should be corrected for germination rates (Chapter 8).

A higher seeding rate for late-planted seeds is generally needed to compensate for the reduced number of tillers produced. The 28 seeds/ft<sup>2</sup> are based on recommended planting dates and good seedbed conditions. Remember, wheat is a cool-season crop and produces more tillers at cool to moderate temperatures than at higher temperatures. Therefore, the higher seeding rates will help compensate for reduced tillering.

Many growers prefer to plant bushels or pounds of seed per acre instead of using a planting density quantity like seeds/ft<sup>2</sup> or seeds per foot-of-row. In order to accommodate these growers, the density seeding rates in Table 5.2b have been converted to pound seeding rates. To convert the pound values in Table 5.2b to bushels, divide the number of pounds by the seed lot bushel weight to obtain the number of bushels in the seed lot.

Although many wheat growers measure seeding rates in bushels or pounds, it’s a good idea to verify the amount of seed being planted. Table 5.2c provides guidance on how to quantify seed delivery (number of seeds per foot-of-row). Included in the footnotes of Table 5.2c are two additional ways in which the table can be used to facilitate seeding plans or planting operations.

Table 5.2a. The number of pure-live-seed (PLS) per foot-of-row required to deliver the recommended seeding rate depending on planting conditions and row space. In a given seed lot, PLS = germination % x purity %.						
Planting conditions		Drill row spacing - inches				
		6	7	7.5	8	10
<i>Recommended rates:</i>		----- PLS per foot-of-row-----				
Firm seedbed– 28 seeds/ft <sup>2</sup>		14	16	18	19	23
Late seeding– 42 seeds/ft <sup>2</sup> (50% increase)		21	25	26	28	35

Table 5.2b. Spring wheat planting rates listed by seed size or seed count, and planting conditions that generally result in about one million seedlings per acre at emergence.			
	Planting conditions		
Seed size by seed count	Firm seedbed (28 PLS/ft <sup>2</sup> )	Loose seedbed (35 PLS/ft <sup>2</sup> )	Late seeding (42 PLS/ft <sup>2</sup> )
No./lb	----- PLS—lbs/A -----		
17,000	72	90	108
16,000	76	95	114
15,000	81	102	122
14,000	87	109	131
13,000	94	117	141
12,000	102	127	152
Calculations are based on 100% PLS and 90% emergence.			

**Table 5.2c. The number of seeds per foot-of-row required to attain various seeding populations per acre using six row widths.** The blue values are populations of about 1.2 million seeds per acre.

Seeds per foot-of-row <sup>a</sup>	Row width - inches <sup>b</sup>					
	6.0	7.0	7.5	8.0	10	12
	----- Seeds per acre -----					
1	87,120	74,674	69,696	65,340	52,27	43,560
2	174,240	149,349	139,392	130,680	104,544	87,120
4	348,480	298,697	278,784	261,360	209,088	174,240
6	522,720	448,046	418,176	392,040	313,632	261,360
8	696,960	597,394	557,568	522,720	418,176	348,480
10	871,200	746,743	696,960	653,400	522,720	435,600
12	1,045,440	896,091	836,352	784,080	627,264	522,720
14	1,219,680	1,045,440	975,744	914,760	731,808	609,840
16	1,393,920	1,194,789	1,115,136	1,045,440	836,352	696,960
18	1,568,160	1,344,137	1,254,528	1,176,120	940,896	784,080
20	1,742,400	1,493,486	1,393,920	1,306,800	1,045,440	871,200
22	1,916,640	1,642,834	1,533,312	1,437,480	1,149,984	958,320
24	2,090,880	1,792,183	1,672,704	1,568,160	1,254,528	1,045,440
26	2,265,120	1,941,531	1,812,096	1,698,840	1,359,072	1,132,560
28	2,439,360	2,090,880	1,951,488	1,829,520	1,463,616	1,219,680
30	2,613,600	2,240,229	2,090,880	1,960,200	1,568,160	1,306,800
32		2,389,577	2,230,272	2,090,880	1,672,704	1,393,920
34		2,538,926	2,369,664	2,221,560	1,777,248	1,481,040
36		2,688,274	2,509,056	2,352,240	1,881,792	1,568,160

<sup>a</sup>*If seeds per foot-of-row equals 1*, the number of seeds per acre equals the number of linear feet-of-row per acre for that row width. For example, if row width equals 10, the linear feet-of-row per acre equals 52,272 feet.

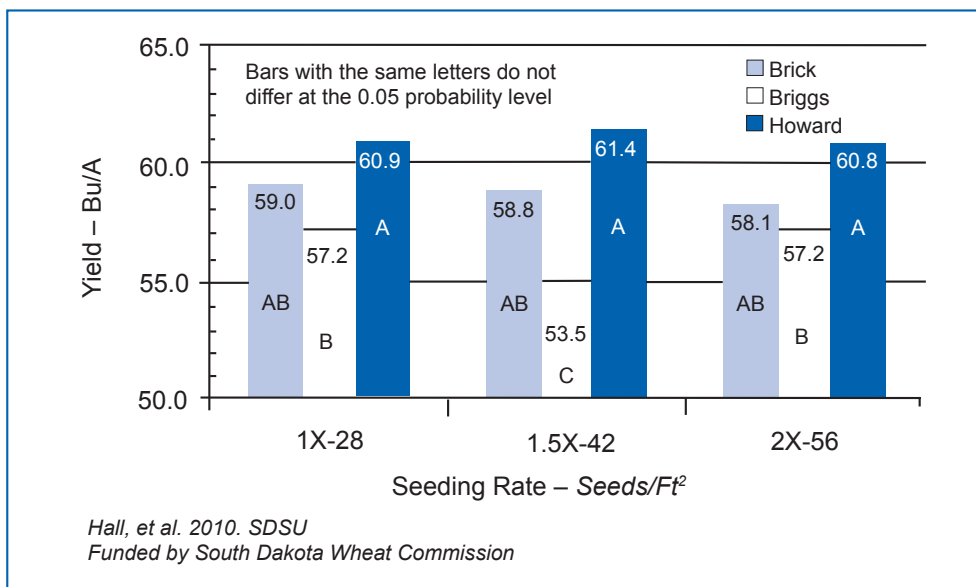
<sup>b</sup>*If row width equals 12*, the number of seeds per acre for a given number of seeds per foot-of-row equals the number of seeds/ft<sup>2</sup>. For example, if seeds per acre equals 1,219,680, the number of seeds/ft<sup>2</sup> equals 28.

#### ***Recent South Dakota spring wheat plant population research***

The 1.2 million seeds/acre seeding rate recommendation was tested in research conducted in 2003, 2004, and 2010 at Warner and South Shore, South Dakota (Northeast Research Farm). Partial results from the 2010 spring wheat seeding rate study funded by the South Dakota Wheat Commission are shown in Figure 5.1. The yield averages from the 1.2 (1X) and 2.4 (2X) million seeds/acre seeding rates were similar. The yield averages from the 1.8 (1.5X) million seeds/acre seeding rates were lower than the 1X and 2X seeding rates. This lack of yield increase, considering the increased seeding rates in 2010, was similar to the results obtained in 2003 and 2004. The lack of yield increases with increasing population was attributed to a reduction in the number of heads/planted seed (Table 5.3). This suggests that higher seeding rates are not justified when using typical South Dakota cultivars that tiller. A higher seeding rate is needed when a 'low-tiller' variety is planted.



**Figure 5.1. The spring wheat yield response to the significant variety x seeding rate interaction at Warner, SD (2010).** Yield values followed by the same letter do not differ significantly at the 0.05 level of probability.



**Table 5.3. The effect of plant population on the number of heads produced for each seed planted.**

Planted populations	Brick	Briggs	Howard
<i>Million seeds/acre</i>	<i>----- Heads/seed planted -----</i>		
1.0	2.2	2.6	2.5
1.8	1.4	1.7	1.8
2.4	1.2	1.1	1.3

### **Seeding depth**

The recommended seeding depth for spring wheat is 1 to 2 inches. At depths less than one inch, there is a higher risk of poor seed-soil contact and poor emergence, especially when the seed bed is rough and/or dry. Spring wheat does not generally exhibit as much, if any, hypocotyl elongation compared to winter wheat, so there can be a danger of planting spring wheat too deep. It is strongly suggested that spring wheat should never be planted less than 1 inch or more than 3 inches deep.

### **Additional information and references**

*South Dakota field crops—planting to harvest. 1979. South Dakota Agricultural Statistics Service.*

*South Dakota—seeding to harvest. September 1995. South Dakota Agricultural Statistics Service.*

Simmons, S.R., E.A. Oelke, and P.M. Anderson. 1995. Growth and development guide for spring wheat. University of Minnesota, WWW-F0-02547. Available at <http://www.extension.umn.edu/distribution/cropsystems/dc2547.html>

### **Acknowledgements**

*Support for this chapter was provided by South Dakota State University, SDSU Extension, South Dakota Experiment Station, and the South Dakota Wheat Commission. The efforts of Kevin Kirby and Shawn Hawks, Agriculture Research Managers/Specialists for the South Dakota Crop Performance Testing Program are gratefully acknowledged.*

---

Hall, R.G. 2012. Spring wheat planting guide. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). iGrow Wheat: Best Management Practices for Wheat Production. South Dakota State University, SDSU Extension, Brookings, SD.



## CHAPTER SIX

# Selecting Spring and Winter Wheat Cultivars For Optimum Profitability

Bob Fanning ([Robert.Fanning@sdstate.edu](mailto:Robert.Fanning@sdstate.edu))

Darrell L. Deneke ([Darrell.Deneke@sdstate.edu](mailto:Darrell.Deneke@sdstate.edu))

The selection of a wheat cultivar or variety may be one of the most important management decisions a wheat grower can make, and choosing one or more wheat varieties to plant can be crucial to your operation. By selecting varieties with different genetic backgrounds, you can increase the resistance traits of certain pests and increase the genetic yield potential for a specific area.

Picking the right variety for your area takes more than choosing last year's local top yielder. Given the high amount of climatic variability across South Dakota, it is important to select a variety that will yield well across many environments (Chapter 34). Choose a variety that is consistent in yield even if the environments vary from location to location.

When comparing yields over years, always compare like yield averages; that is, one-year with one-year, two-year with two-year, and three-year with three-year averages. Always determine if the data is valid. The coefficient of variation (CV) value is a measure of experimental error. The CV is the standard deviation divided by the mean. [http://en.wikipedia.org/wiki/Coefficient\\_of\\_variation](http://en.wikipedia.org/wiki/Coefficient_of_variation). Both of these values can be calculated in Excel. For additional information and examples, consult the publication, *Mathematics and Calculations for Agronomists and Soil Scientists*, Clay et al. (2010).

Ideally, yield trials should have CV values of 15% or less; if not, the trial contains too much experimental error for accurate recommendations. The yields for the different varieties should be compared using an appropriate statistical analysis. One of the easiest tests to use is

a *t test* (Clay et al. 2010). If an experiment contains more than two treatments, then a least significant difference (LSD) can be used to compare the averages. Consider, the varieties will differ if the difference between two varieties is greater than the LSD value, but if the difference is equal to or less than the LSD value, the varieties do not differ significantly. If you have questions, you should contact an Extension specialist.

Yield is only one parameter to consider when choosing a variety. Insect and disease resistance, tolerance to frost and winterkill in the case of winter wheat, hardiness, crop maturity, straw strength, milling characteristics, and other traits are important considerations as well.

South Dakota produces an annual report that compares the results from last year's variety yield trials. For example, the report from 2011 is located at <http://igrow.org/up/resources/03-3001-2011.pdf> (Hall et al. 2011). This report provides the characteristics and performance of spring wheat varieties tested in South Dakota in 2011, and recommendations for 2012. It is an excellent guide to select one or more varieties with the agronomic characteristics suitable for a grower's area and production system.

When considering yield, look for varieties that have performed well at locations near your farm over the past three years. This publication also contains a "Recommended" and "Acceptable/Promising" list of varieties, with notations as to the Crop Adaptation Area(s) they are suitable to be grown in, and a map of Crop Adaptation Areas for South Dakota. The following series of graphs (Fig. 6.1 and Fig. 6.2) offer a visual comparison of the spring and winter wheat varieties tested in 2011, based directly on the information in the 2011 Annual Report. Traits and characteristics are rated:

- P = *poor*
- F = *fair*
- G = *good*
- VG = *very good*
- E = *excellent for lodging resistance*

VS, S, MS, MR, R and VR for disease reactions are given a numerical value to allow charts to be generated.

**Figure 6.1. Spring wheat cultivar impact on measured yields, protein, and pest resistance.**  
(continues on next page)

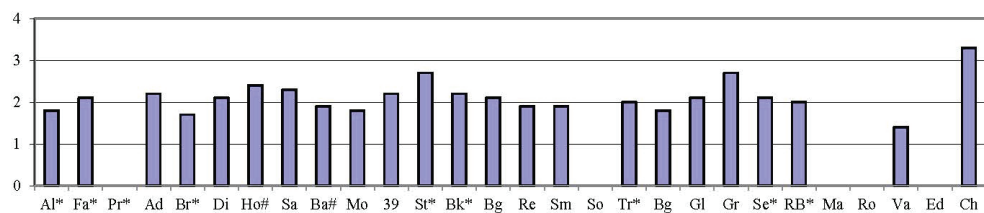
**Spring Wheat Yields & Characteristics (2011 SD CPT results)**  
\* - Recommended Varieties, # - Acceptable/Promising



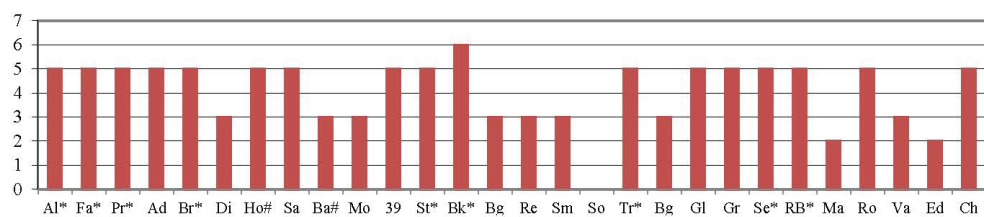
# Spring Wheat Yields & Characteristics (2011 SD CPT results)

\* - Recommended Varieties, # - Acceptable/Promising

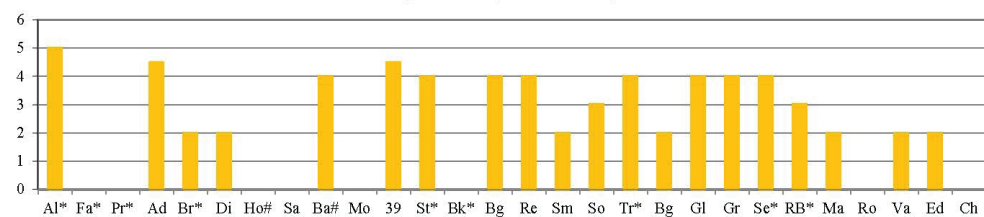
## Lodging (1=Poor, 5=Excellent)



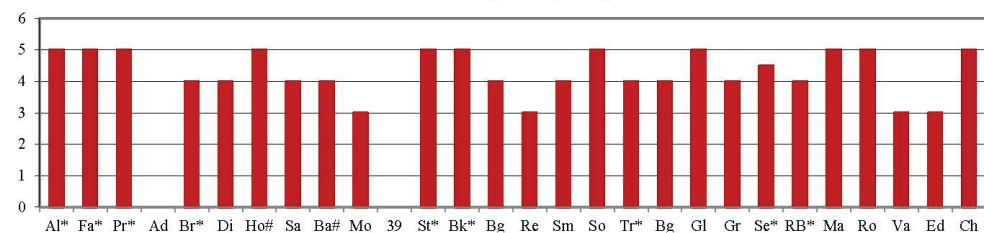
## Scab - FHB (1=VS, 6=R)



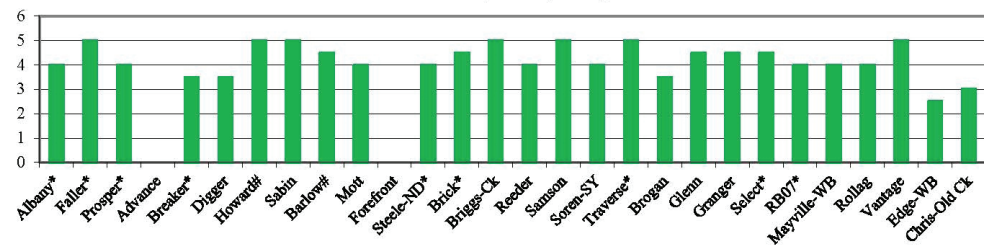
## Stripe Rust (1=VS, 5=R)



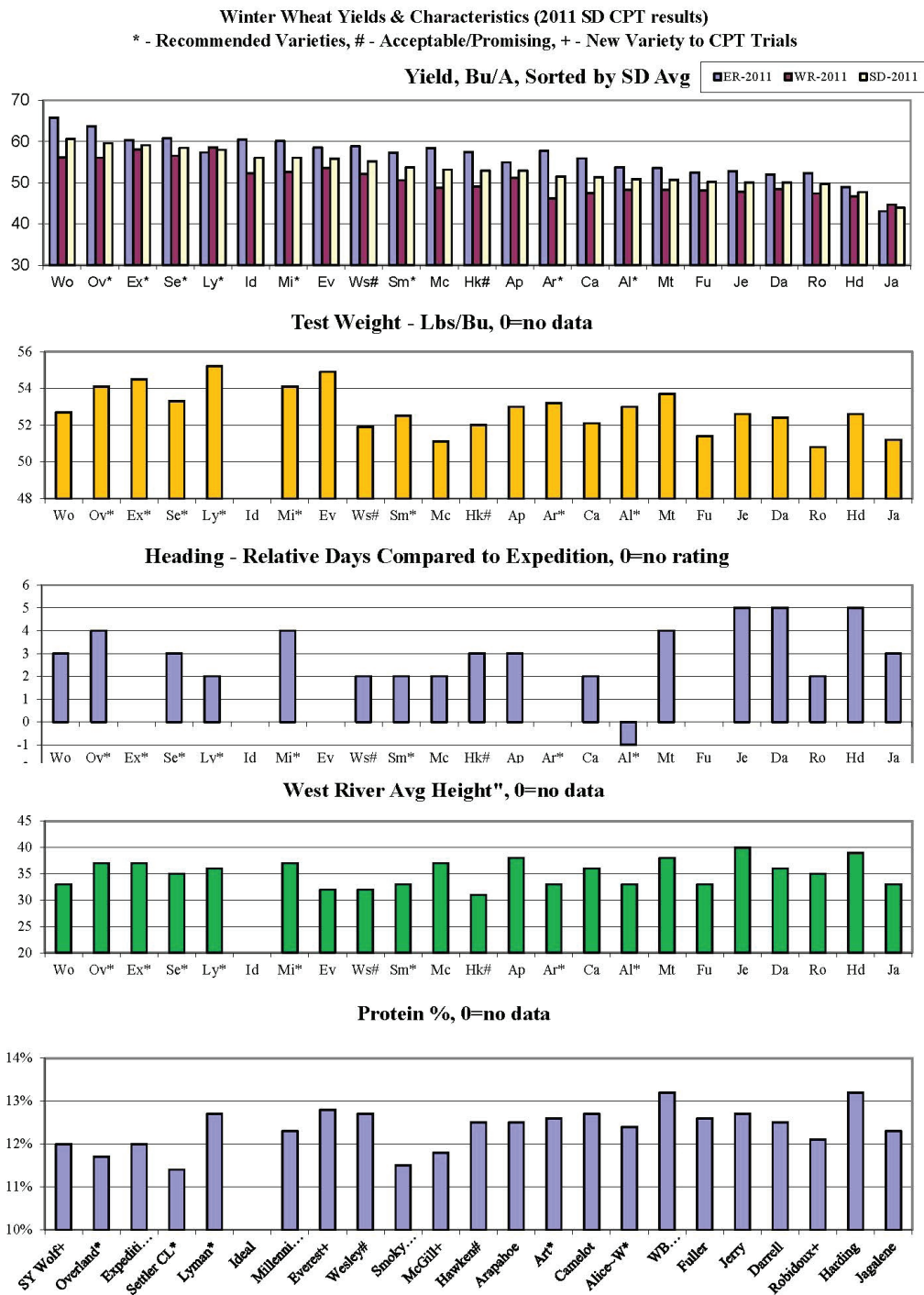
## Stem Rust (1=VS, 5=R)



## Leaf Rust (1=VS, 5=R)



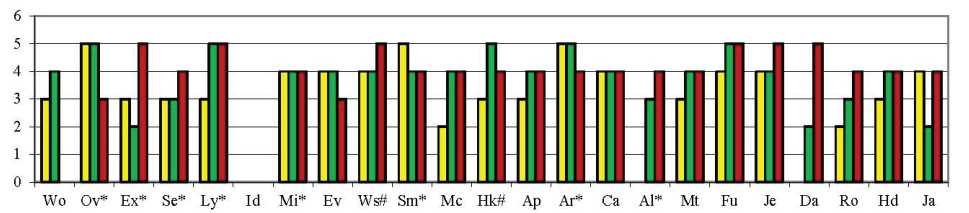
**Figure 6.2. Winter wheat cultivar impact on measured yields, protein, and pest resistance.**  
(continues on next page)



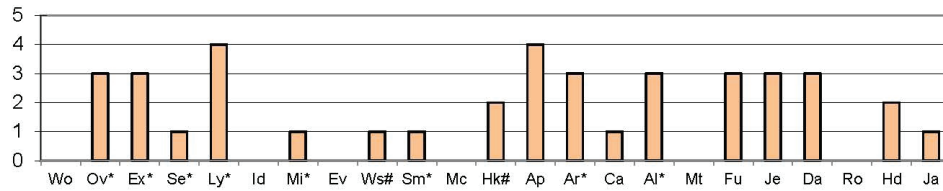


**Winter Wheat Yields & Characteristics (2011 SD CPT results)**  
 \* - Recommended Varieties, # - Acceptable/Promising, + - New Variety to CPT Trials

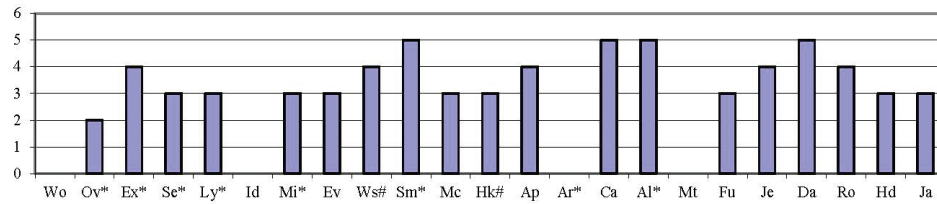
**Stripe, Leaf & Stem Rust - 1=VS, 5=R (0=not rated)**



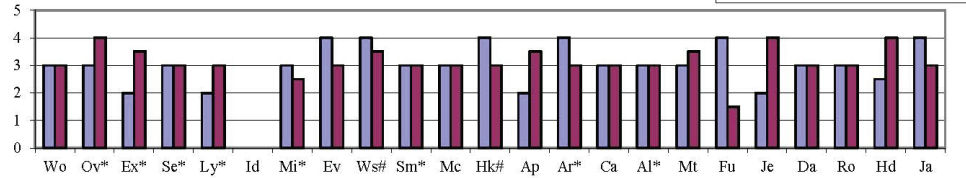
**Scab (FHB), 5=tolerant, 1=susceptible (0=not rated)**



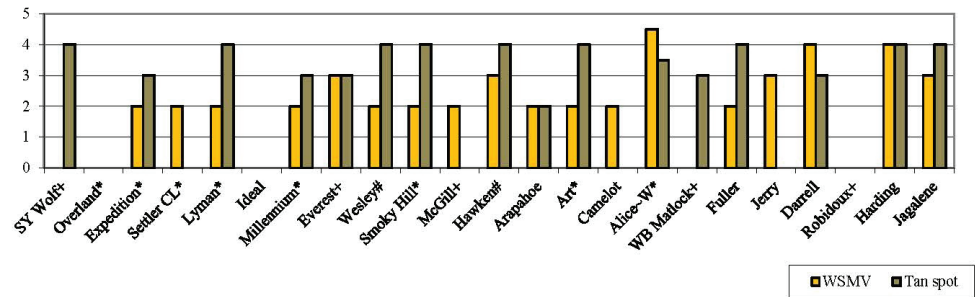
**End use Quality - 1=P, 5=E (0=no rating)**



**Lodging & Winter Hardiness - 1=P, 4=E, 0=no rating**



**Wheat Streak Mosaic Virus & Tan spot - 1=VS, 5=R, 0=no rating**



Variety selection is an important step in reducing production risks and maximizing wheat yields and economic returns. By considering varieties that have specific resistance or tolerance traits to certain diseases and insects, growers can reduce impact costs such as fungicides and insecticides. This is one of the basic concepts of integrated pest management (IPM). Selecting cultivars that are best for your local growing conditions and maintaining healthy crops is an excellent preventative cultural practice against pests.

Resistant cultivars have a built-in tolerance or resistance to attack by certain pests. The degree of resistance will vary from slight to almost complete. However, no plant variety is resistant to all wheat pests (diseases and varieties), so you must carefully evaluate varieties from local testing programs.

The resistance mechanism basically works in the three main ways. *Chemicals in the plant* repel the pest, or prevent it from completing its life cycle. *The plant is more vigorous* and suffers less damage from pest attack, or is not susceptible to the disease. And the *plant has physical characteristics* making it more difficult for pest attack.

Because of wheat variety testing programs, many wheat varieties have disease and insect resistance ratings. These ratings give you an idea of the rate of resistance or susceptibility to common insects and diseases for an area. For more information from yield studies conducted between 2010 and 2011, see Hall et al. (2011). For information on wheat diseases, see Chapter 23.

Diseases that should be considered include Fusarium head blight or scab, wheat streak mosaic virus, leaf rusts, bunts and smuts, barley yellow dwarf virus, wheat soil borne mosaic viruses, powdery mildew, stripe rust and stem rusts.

Another consideration to keep in mind with disease resistance traits is many are developed for specific races or strains of the disease pathogen. Over time, these races can change, making the variety that was once resistant susceptible to the disease. This is the reason new varieties with specific disease-resistant traits are continually being developed.

Insect resistance or tolerance works much the same way, utilizing bred-in characteristics of the plant variety that may have a chemical in the plant that repels the specific insect. Additionally, the plant variety may have a specific physical characteristic that makes it more difficult for the insect to attack or cause significant damage. For additional information on insects, see Chapter 22.

Many wheat varieties have been developed that have specific resistance or tolerance to Hessian fly, greenbugs, Russian wheat aphid, wheat stem saw fly, and others. In many cases, even moderate resistance is enough to avoid extensive insecticide treatments. However, like diseases, insect bio-types may develop, overcoming the plant resistance so considerable efforts in plant breeding are needed to maintain these traits.

Weed suppression can even be influenced by variety selection. Selecting wheat varieties or cultivars that can be more competitive than the weeds may be considered. Wheat traits that improve competitiveness with weeds would include rapid growth after seeding, greater seedling vigor, good tillering characteristics, and greater leaf area development to close the crop canopy quicker. In the case of winter wheat, wheat varieties with good winter and cold hardiness are important considerations.

Another tool available to winter wheat growers for improved weed control for specific weeds such as jointed goatgrass, feral rye, downy brome and some other hard to control grasses is the *clear field wheat technology*. Wheat cultivars that have been selected for this technology have a specific gene that has tolerance to improve herbicide, commercially known

as Beyond®. This herbicide program has activity on specific grassy and broadleaf weeds, and can be used on the selected wheat cultivars that are sold commercially as clear field wheat.

The cultivars containing this specific gene may be treated with an imazamox herbicide with minimal risk of crop injury. However, winter wheat cultivars that do not contain this specific tolerance gene would be seriously injured or killed when treated with this particular kind of herbicide.

One concern to consider is the development of herbicide-resistant weeds so you need to continually observe your weed populations and utilize an herbicide rotation program. Additional information on weeds or weed control is available in Chapters 24, 25, and 26.

Growers should select varieties with good test weights, milling, and baking characteristics. Many wheat varieties have trait information on these characteristics.

Another trait to consider is the wheat varieties' coleoptile length. The coleoptile is the part of the seed that pushes upward through the soil after planting. Generally speaking, varieties with a longer coleoptile can be planted deeper to get to available moisture. This is important for more arid areas or if it looks like a year where adequate moisture may be a concern. Ratings for coleoptile length are commonly part of the variety testing information available to growers.

Variety or cultivar selection involves many considerations and there are tools available to help you make the most informed decisions. Every growing season will differ, so you need to consider variety-testing data that summarizes several years and locations. Choose those varieties that have performed the best at multiple locations near your operation and include information on those traits that are important to you. As stated in the beginning of this chapter, variety selection is one of the most important economic and management decisions that you as a grower can make.

#### Additional information and references

Clay, D.E., S.A. Clay, C.G. Carlson, and S. Murrell. 2010. *Mathematics and Calculations for Agronomists and Soil Scientists*. International Plant Nutrition Institute. Available at <http://ppi-store.stores.yahoo.net/maandcaforag.html>

Hall, R., J. Rickertson, K. Kirby, S. Hawks, and B. Swan. 2011. *Annual Report: Spring wheat test results for 2011 traits, yield averages, and variety recommendations for 2012*. Available at <http://igrow.org/up/resources/03-3001-2011.pdf>

#### Acknowledgements

Support was provided by USDA through the NIFA/ IPM program.

---

Fanning, B., and D.L. Deneke. 2012. Selecting spring and winter wheat cultivars for optimum profitability. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.



## CHAPTER SEVEN

# Cover Crops Following Wheat

Peter Sexton ([Peter.Sexton@sdstate.edu](mailto:Peter.Sexton@sdstate.edu))

Cover crops can provide forage for livestock, improve soil quality, and help manage excess water. This chapter provides an overview of cover crops and basic information needed to determine what and when to plant.

### Cover Crop Rules of Thumb

- The smaller the seed size, the longer it will take for the plant to put on substantial growth. Clovers will take much longer to put on growth than peas, lentils or vetches.
- When selecting species and planting densities, be sure to consider disease issues for the following crop.
- Most cool and warm season grasses (including oats, barley, rye, sorghum and corn) can act to varying degrees as secondary hosts for the wheat curl mite.
- Choose cover crops that are broadly different from the next cash crop.
- To decrease surface residue plant cover crops high in N (legumes), or low in fiber (Brassicas).
- To increase residue, plant cover crops high in C and fiber (millet or sorghum).
- Plant as soon as possible.
- Buy seed with an objective of minimizing seed cost.



**Figure 7.1. Cover crop planted into wheat stubble.** (Photo courtesy of Cheryl Reese, SDSU)

In South Dakota an opportunity exists for cover crops to be planted following the harvesting of small grains in July and August. Cover crops capture energy from sunlight that would otherwise be lost from the ecosystem. Benefits of cover crops may include: reduced erosion, decreased compaction, potential for reducing N losses and reduced N fertilizer requirements, increased trapping of snow, improved traffic ability, increased production of game birds, improved nutrient recycling, and improved management of excess water.

Like any tool, cover crops can have a negative impact, if not used wisely. For example, cover crops have the potential to use soil moisture that otherwise might be available to the following crop. They can also reduce the following yield in the cash crop, if they do not winterkill. For cover crops that winterkill, the effect on soil moisture is dampened by the recharge of soil moisture over the winter. Cover crops that grow into the following spring will use more moisture, and legumes will fix more N than those that winterkill.

Depending on the circumstances, an overwintering cover crop may be a positive or a negative factor. In a wet spring, the use of moisture and improved traffic ability, associated with the overwintering cover crop, may be an asset. In a dry spring, the overwintering cover crop may be a liability. Obviously, the dryer the environment, the more likely that water use by the cover crop can have a negative impact on the following year crop yields. In many situations the water used by the cover crop can be replaced by increased snow capture.

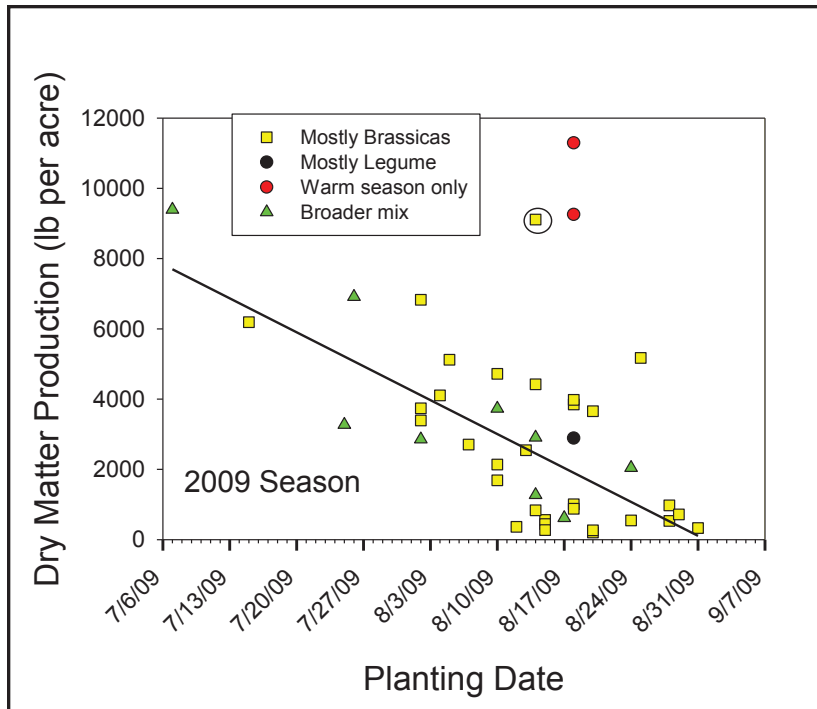
### ***Planting date and composition***

Delaying planting reduces the amount of generated biomass (Fig. 7.2). This reduction is attributed to a decrease in heat units. Cover crops can be planted as a solid stand of a single species or a mixture of plants. Solid stand, planting rates, planting depths, and salt tolerances are provide in Table 7.1. For mixtures, selected seeding rates are provided in Table 7.2. Many growers, who use cover crops, plant a mixture because:

1. A mixture is more broadly adapted to varying soil conditions.
2. A mixture helps manage climate and soil variability.
  - a. When N is limiting, legumes, which fix N, will be favored.
  - b. When N is plentiful, grasses and Brassicas can “soak up” the extra N.
3. A mixture enhances cropping system diversity and increases the rotation benefits.

**Table 7.1. Seeding depth, salt tolerance, and full seeding rate of selected cover crops.** To determine seeding rates of mixtures, multiple the full rate times the desired composition (see salinity and other compositions in Table 7.2).

Plant	Composition %	Rate lbs/acre	Plant	Seeding depth inch	Salt tolerance rating	Seeding rate lbs/acre
Canola	30	5×0.3=1.5	Canola	0.25-0.75	good	5
Sugar beet	30	4×0.3=1.2	Turnip	0.25-0.5	poor	4
Barley	40	50×0.4=20	Radish	0.25-0.5	poor	8
			Barley	0.75-2	good	50
			Rapeseed	0.25-0.75	good	5
			Oat	0.5-1.5	fair	70
			Lentil	1-1.5	poor	30
			Sugar beet	0.25-0.5	good	4



**Figure 7.2. On-farm observations of dry matter production relative to planting date in 2009.** The warm-season only points and the circled point were not included in the trend line analysis for the 2009 season. (Jeff Hemenway, USDA-NRCS)

### *General categories of cover crops*

Brassicas (e.g., radish, turnips, and canola) are well adapted to cool fall conditions. Brassicas have relatively low seeding rates, and will help alleviate soil compaction (especially forage radish). A disadvantage with Brassicas is that they do not form mycorrhizal associations. There is also some concern that Brassicas may act as a host for white mold, which can be a disease problem in soybeans. Usually infection by the white mold fungus occurs at flowering, so Brassicas that don't flower before winterkill are less of a concern.

Warm-season grasses (e.g., sorghum, millets, sudangrass, and corn) have the greatest potential for rapid accumulation of dry matter under warm conditions, tolerate drought stress better than many other species, and have roots that form associations with mycorrhizal fungi. Mycorrhizal associations help plants take up water and nutrients. N contained in the residue may not be readily available to the subsequent crop.

**Table 7.2. Some cover crop mixes suggested by the NRCS for different grazing and soil improvement purposes.** (from Jason Miller, USDA-NRCS)

Purpose	Species	Percent	Seed Rate in Mixture (lb/ac)
Grazing	Lentil	30%	9
	Turnip	30%	1.2
	Oat	30%	21
	Radish	10%	0.8
Salinity	Canola/Rapeseed	30%	1.5
	Sugar beet	30%	1.2
	Barley	40%	20
Compaction	Canola/Rapeseed	10%	0.5
	Lentil	25%	7.5
	Radish	55%	4.4
	Flax	10%	2
Warm-season Grazing	Pearl Millet	60%	15
	Cowpea	40%	12
Residue Cycling & Compaction	Canola/Rapeseed	30%	1.5
	Radish	30%	2.4
	Lentil	40%	12
Use of Spring Moisture & N Fixation	Winter Rye	50%	30
	Hairy Vetch	50%	7.5
Warm-season Grazing & Compaction	Cowpea	20%	6
	Pearl Millet	20%	5
	Sorghum-sudan	20%	5
	Turnip	20%	0.8
	Radish	20%	1.6
Residue Cycling	Canola/Rapeseed	50%	2.5
	Lentil	50%	15

Cool-season grasses (e.g., oats and barley) are frost tolerant and adapted for growth in cool fall conditions. If the plant tissue becomes fibrous, N contained in the residue may not be readily available to the following crop. These residues may decompose slower than Brassicas. This group of plants will also form mycorrhizal associations.

Cool-season legumes (e.g., peas, lentils, hairy vetch, chickling vetch, and clovers) tolerate cool conditions and resist frost. Some members of this group, such as hairy vetch, may overwinter. Cool-season legumes:

- 1) produce high quality forage,
- 2) can fix N,
- 3) produce residue with a low C:N ratio, and
- 4) have slower growth rates than many grasses.

*It is noteworthy to point out that chickling vetch seeds contain toxins that may injure livestock, particularly horses, if consumed.* Residues from cool-season legumes are generally rapidly mineralized, allowing the N contained in their biomass to be partially available to the following crop. This group of plants forms mycorrhizal associations.



Warm-season legumes (e.g., cowpea, mungbean, and soybean) are relatively heat tolerant, but not frost tolerant, and therefore they will not have a long fall growing period. This group of plants:

- 1) fixes N under the proper circumstances,
- 2) has growth rates that are slower than many grasses, and
- 3) forms mycorrhizal associations.

Sunflower, flax, buckwheat, and sugar beets are broadleaved plants that have unique characteristics. Sunflower is well adapted to warm temperatures and has roots that elongate faster than many other crops. Flax is shallow rooted and forms a high level of mycorrhizal associations. Buckwheat develops a canopy very rapidly, sets seeds quickly, but is not frost tolerant, and it is an efficient P scavenger. Sugar beets are tolerant of frost and salinity, but do not appear to form mycorrhizal associations.

### ***Selecting a cover crop mixture***

There are several important factors to consider in selecting a cover crop mixture. Most important are the objectives you have in mind: forage production, reduce residue, increase residue, ameliorate soil compaction, among others. Table 7.2 provides information on seed rates for a number of cover crop mixes developed for different purposes. When selecting species and planting densities, farmers should consider their impact on diseases for the following crop. Cover crops that share diseases or pests with whatever comes next in the rotation cycle should be avoided. If the next crop is corn (a warm-season grass), then cool-season legumes and Brassicas might be a good choice. If the next crop is wheat, it is advised to avoid grasses altogether in order to deny the wheat curl mite entry to the field.

Most cool and warm season grasses (including oats, barley, rye, sorghum and corn) can act to varying degrees as secondary hosts for the wheat curl mite (Wegulo et al. 2008). Wheat curl mite acts as a disease vector that carries the wheat streak mosaic virus. The mite prefers wheat and will multiply most rapidly on wheat; therefore, control of volunteer wheat is most important for controlling this disease and preventing its spread to nearby wheat crops. Selection of cover crops that do not act as hosts for the mite also will help to limit mite populations in fields that will be seeded back into wheat.

Generally it is a good idea to choose a cover crop that is completely different from the next crop. Using this approach will maximize the rotation benefits and avoid disease problems. For example, some legumes such as hairy vetch and cowpeas can act as hosts for soybean cyst nematode, while rye can become a contaminant in wheat. In this regard, Brassicas are often a valuable component in cover crop mixes because they differ from many cash crops grown in South Dakota (except for canola). They require a low seed rate and decompose quickly; their volunteers are easy to control with herbicides. However, as noted earlier, Brassicas can act as a host for white mold, particularly if they produce flowers.

To decrease residue on the soil surface, cover crops that are high in N, such as legumes, or those that produce succulent growth, such as radishes, are a good choice. To increase residue, cover crops that are high in C and fiber, such as millet or sorghum, may be good choices. Water use by the cover crop also needs to be considered. Cover crops will use some moisture in the fall, but they may also help trap snow to recharge the profile. The impact on

soil moisture depends upon soil type, rainfall patterns, and the relative need for moisture in the following crop.

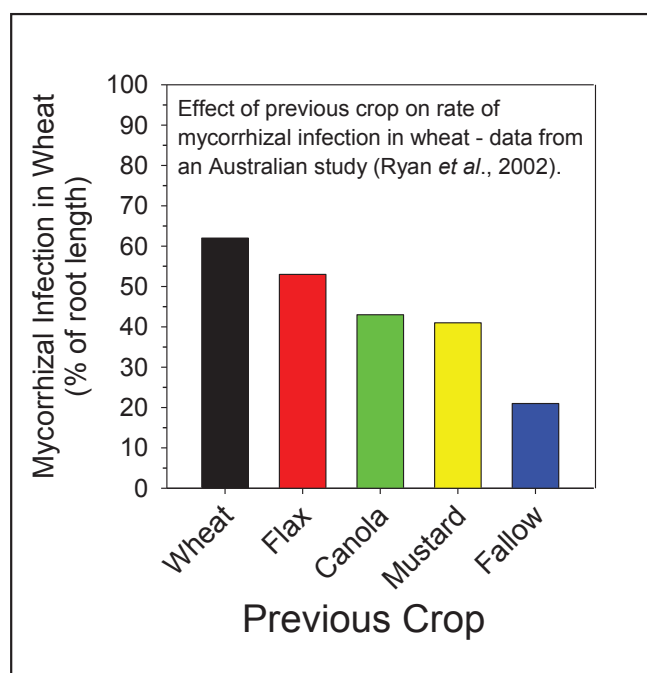
Another consideration is the potential of the cover crops to overwinter, such as winter rye, winter triticale, and hairy vetch. A cover crop that overwinters can provide more forage in the spring and will use more soil moisture, compared to cover crops that winterkill.

### ***Cover crops ahead of wheat-on-wheat on wheat rotations***

When considering cover crops in a wheat-following-wheat rotation, disease pressure and water use must be considered. With winter wheat following spring wheat, there is not enough time between the spring wheat harvest and the winter wheat seeding for a cover crop to put on much growth. However, when spring wheat follows winter wheat, there is enough time for the cover crop to produce biomass. By avoiding grasses in this rotation, disease problems (Chapter 23) such as crown rot and wheat streak mosaic virus (carried by the wheat curl mite) may be lessened.

Cover crops can also impact populations of beneficial microbes such as mycorrhizae. Figure 7.3 shows partial data from a study conducted in Australia looking at effects of previous crops on mycorrhizae populations in the following wheat crop. Even cover crops that are not hosts to mycorrhizae, namely canola and mustard in this study, showed increased infection in the following wheat crop.

Soil moisture is another consideration in wheat-on-wheat rotations. Some judgment is needed to consider effects of a cover crop on soil moisture for the following wheat crop. On the plus side, one would expect cover crops to help catch snow and contribute to improved soil structure, which would mean better infiltration rates and root growth for the following crop. On the negative side, the water use by the cover crop could lead to a drier seed bed.



**Figure 7.3. Mycorrhizal infection in wheat as influenced by prior crop.**  
(Modified from Ryan *et al.* 2002)

### ***N cycling***

Composition of the cover crop mix, N uptake by the cover crops, total biomass produced, along with climate conditions the following season, all influence residue decomposition and how much N will be released for the following crop. Legumes and Brassicas tend to breakdown quickly and release a larger portion of their N than do grasses. For some systems, additional N fertilizer is required for the following crop. For example, for immature grasses, 25% of the N in the grass may be released to the following crop; whereas with more mature grasses, an extra 20 to 30 lb of N per acre may be required to compensate for N tied up in the residue.

The potential for leaching of N out of the soil profile is another factor to consider when weighing the value of cover crops. Cover crops, particularly cool-season grasses and Brassicas that grow well into the fall, will take up soil N and prevent its loss through leaching or denitrification. In denitrification, nitrogen is lost from the soil to the atmosphere as nitrous oxide (N<sub>2</sub>O) or nitrogen gas (N<sub>2</sub>). Both nitrate leaching and denitrification generally occur under high moisture conditions. Cover crops can reduce these losses by taking up the inorganic N from the soil (Chapter 11). Research to determine the N credit from cover crops is currently being conducted. Data from around the region suggests that:

1. A legume cover crop mix might produce a 20 to 25 lbs N per acre credit.
2. Radish cover crop might have a credit of 10 to 15 lb N per acre.
3. Grasses might require an additional 15 to 30 lb extra N/acre.
4. When the following crop is a small grain, it may be better not to assign an N credit because the more rapid maturity of the small grain means there is less time for the cover crop residue to decompose before the grain crop matures.

As more research data becomes available, these estimates may be changed.

Grazing can also have an impact on the rate of N release. Grazing will accelerate tissue decomposition and nutrient release. Data on the effect of grazing on yield of the following grain crop is scarce. Work done in the southeastern U.S. with grazed and ungrazed grass plots indicates that, while grazing caused small increases in soil compaction, it increased yields of the following grain crop due to more rapid nutrient cycling (Jim Marois, University of Florida, personal communication). Given the uncertainty and the consequences of under-applying N, farmers are advised to keep good records of cover crop growth and changes in soil N before and after the following crop to help guide their decisions over time.

### ***Residue decomposition***

The N concentration of the crop residue, along with temperature and moisture, has a large impact on the rate of residue breakdown. Cover crops reach down into the soil and pull N up through their root systems to support top growth. When the cover crop dies and decomposes, N is released at or near the soil surface. If the cover crop decomposes rapidly, as is typical of Brassicas and legumes, then it appears that this N may contribute to accelerated decomposition of previous crop residues. In the following growing season, there may be less residue. On the other hand, if the cover crop is slow to decompose, the N it takes up will be sequestered in the cover crop residue and the decomposition of the cover crop may tie up N, rather than release it. In this situation the cover crop will contribute to increased residue on the surface as well as increase the N requirement of the following crop. This is more likely to occur with non-legumes and non-Brassicas, especially if they have a high C:N ratio or are fibrous/stemmy in growth.

### ***Salinity***

Soil salinity is an increasing problem in South Dakota. Salt tolerances of selected cover crops are provided in Table 7.1. This topic is discussed further in Chapter 19.

### ***Herbicide carryover***

Carryover of herbicide activity can injure cover crops. Refer to the product label for plant back restrictions for cover crops of interest. A partial listing of several compounds used in wheat production with estimated plant back restrictions in months for different cover crop groups is given in Table 7.3. Chapter 25 discusses herbicide recommendations in wheat.

**Table 7.3. Partial listing of several herbicides that may have carryover effects on cover crops.** This list is provided to give a preliminary estimate of potential for herbicide carryover. It is not exhaustive or complete, so refer to the label or consult with your herbicide retailer for more specific information on individual cover crop species. If uncertain, conduct a bioassay to see if there is residual activity of the herbicide in question.

Herbicide	Cover Crop Group		
	Brassicas	Legumes	Warm-season Grasses
	Months		
Olympus® <i>Propoxy-carbazine</i>	12 to 24	12 to 24	12
Maverick® <i>Sulfosulfuron</i>	22	22	22
PowerFlex® <i>Pyroxsulam</i>	9	9	9
Everest® <i>flucarbazone</i>	9 to 24	9 to 24	11 to 24
Ally® <i>metsulfuron</i>	22	22	12

#### Additional information and references

<http://www.mccc.msu.edu/>

[http://www.sdnottill.com/Field\\_Facts\\_wheat\\_cover\\_crop.pdf](http://www.sdnottill.com/Field_Facts_wheat_cover_crop.pdf)

*Managing cover crops profitability.* Published by SARE.

Available at <http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition>

*Potential cover crop seed suppliers.* Available at <http://attra.ncat.org/attra-pub/covercrop.html>

and <http://www.sdnottill.com/Potential%20Cover%20Crop%20Seed%20Suppliers.pdf>

*South Dakota No-Till Association web site.* Available at [www.sdnottill.com](http://www.sdnottill.com)

*South Dakota NRCS home page.* Available at <http://www.sd.nrcs.usda.gov/technical/CoverCrops.html>

*Wegulo, S.N., G.L. Hein, R.N. Klein, and R.C. French. 2008. Managing wheat streak mosaic. EC1871. University of Nebraska-Lincoln, Lincoln, NE.*

#### Acknowledgements

*Thanks and recognition to Mr. Jeff Hemenway and Mr. Jason Miller of the USDA-NRCS for sharing data and comments in the preparation of this chapter. Dr. Dwayne Beck and Dr. Ron Gelderman provided helpful reviews. Partial funding was provided by NC SARE and South Dakota Soybean Research and Promotion Council.*

---

Sexton, P. 2012. Cover crops following wheat. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.





## CHAPTER EIGHT

# Wheat Seed Testing, Pure Live Seed, and Seeding Rates

*Brent Turnipseed* ([Brent.Turnipseed@sdstate.edu](mailto:Brent.Turnipseed@sdstate.edu))

Optimizing wheat yields starts with selecting an appropriate variety with high seed quality. Critical and basic information provided by a seed testing laboratory is the germination percentage, purity analysis (% pure seed, etc.), noxious weed seed examination, and a seed count (#/lb.). This chapter provides an outline for understanding how to use this information.

### ***Standard tests***

To legally sell wheat seed in South Dakota, a standard test—following AOSA seed testing protocols, for germination, purity, and noxious weeds—is required. This standard analysis plus a seed count provides information needed to determine the seeding rate. For example, the seeding rate for a seed batch with a 85% germination requires more seed per acre than a seed batch that has a germination of near 98%.

Not having seed testing information puts the producers and their investment at risk. At a minimum, seedsmen and savvy producers will always have a germination test and a seed count performed, and will clean their seed lot prior to planting. It is always wise to know if the seed is worth cleaning before making that investment (cleaning and/or planting). Planting low quality seed can result in stand failures, over- or under-planting rates, or disease outbreaks. Other tests commonly requested are seed counts, electrophoresis (used to verify the variety), and tetrazolium tests.



### ***Required tests for seed sales***

In South Dakota and most states, three tests are required to be performed before seed can be offered for sale: purity analysis, noxious weed seed exam and a germination test.

- ***Purity analysis test***

This test provides information about the physical make-up of the seed lot (% pure seed, % inert, % other crop seed present, and % weed seed). Percentages are based on weight. This test should be conducted after the seed lot has been cleaned.

- ***Noxious Weed Seed Examination***

In South Dakota, it is prohibited to sell certified wheat seed if noxious weed seed are present in the seed lot. If it contains noxious weed seeds, it must be re-cleaned, sampled, tested, and found to be free of the prohibited weed seed. If restricted weed seeds are found, the seed lot can still be sold, but any restricted weed seed present must be indicated by name and the rate of occurrence (number per pound) on the seed label. The minimum quantity (500 grams) examined in this test is at least five times the purity analysis sample size (100 grams). SD Certified seed cannot have prohibited or restricted noxious weed seed in the seed lots offered for sale.

- ***Germination test***

This test tells you the percent germination of normal seedlings, ones that can be expected to grow and produce plants in the field. Laboratory germination tests are conducted under favorable conditions, which do not always occur in the field. Occasionally there is some dormancy in wheat seed, and the report will show % germination and % dormancy. But typically there is little to no dormancy in wheat seed in the standard germination test when it is conducted one or two months after harvest.

A wheat germination test takes 7 days on old crop wheat (wheat that is from the previous year's production), and 12 days on new crop wheat (wheat harvested in the current year). New crop wheat takes longer as the seed is put through a pre-chill period (five days at 5-10° C) to break any seed dormancy that might occur. Once the wheat is about 4 months old (after harvest), it typically does not need a pre-chill period as dormancy is usually broken.

### ***Additional tests***

- ***Seed count*** – is not a required test, but it is crucial for planting purposes. Seed counts in wheat will vary from 10,000 seeds per pound to as many as 26,000 seeds per pound. Variation is due to varietal differences and growing conditions each year. Knowing your seed count and germination rate are crucial in figuring out planting rates for desired plant population.

- ***Electrophoresis test*** – is used as a varietal verification test. This can be a critical test for assuring that the desired variety is planted. Both hard red spring (HRS) and hard red winter (HRW) wheat are grown in South Dakota, and planting HRS or HRW at the wrong time is a very costly mistake.

- ***Tetrazolium test*** – is a rapid (24-48 hr.) chemical viability test which can be used to estimate the results of the germination test; however, it cannot be used as a legal substitute for the germination test. Results of the TZ test will be phoned, faxed, or e-mailed to the customer when completed.

### ***Pure Live Seed and Seeding Rate Calculations***

Pure live seed (PLS) percentage is important to know when calculating seeding rates, or in calculating which is a better price between seed lots. Let's look at the example labels below and calculate PLS and compare our prices. Let's also consider the other information on the label.

Sample A	Price \$26/bushel	Sample B	Price \$24/bushel
SD Certified Seed		SD Certified Seed	
Certification #xxxxxx	Lot No. 82611	Certification #xxxxxx	Lot No. 82612
Select HRS Wheat	Germination = 96%	Select HRS Wheat	Germination = 85%
Pure Seed = 99.50%	Dormant = 0%	Pure Seed = 99.50%	Dormant = 0%
Inert Matter = 0.48%	Total Viable = 96%	Inert Matter = 0.48%	Total Viable = 85%
Other Crop = 0.01%	Seed Count ≈ 13,600 seed/lb.	Other Crop = 0.01%	Seed Count ≈ 15,040 seed/lb.
Weed Seed = 0.01%		Weed Seed = 0.01%	
Date Tested 11/2/2011	XCO Seed Company	Date Tested 11/2/2011	XCO Seed Company
Noxious Weed Seed: None	Brookings, SD 57006	Noxious Weed Seed: None	Brookings, SD 57006

### ***Calculating Pure Live Seed (PLS)***

$$\% \text{ PLS} = \frac{\% \text{ pure seed} \times \% \text{ total viable}}{100}$$

$$\text{Sample A} - \text{PLS} = \frac{99.50 \times 96}{100} = 95.52\% \text{ pure live seed in one pound of seed}$$

$$\text{Sample B} - \text{PLS} = \frac{99.50 \times 85}{100} = 84.58\% \text{ pure live seed in one pound of seed}$$

Now that you know the PLS, you can calculate the actual cost per bushel (per unit) that each lot costs.

$$\text{Actual cost per bushel of PLS} = \frac{\text{Price per bushel}}{\% \text{ PLS}}$$

$$\text{Sample A} - \text{Priced } \$26/\text{bu.} \quad \text{Actual cost/bu.} = \frac{\$26}{.9552} = \$27.22/\text{PLS Bushel}$$

$$\text{Sample B} - \text{Priced } \$24/\text{bu.} \quad \text{Actual cost/bu.} = \frac{\$24}{.8458} = \$28.38/\text{PLS Bushel}$$

So you can see how much you are actually paying per PLS bushel. Sample B may have looked like the better deal, but it wasn't when you calculate the price per PLS bushel.

Other things that buyers should look at is the "Noxious Weed" heading on the label. SD Certified Seed cannot contain noxious weed seeds in the seed lot offered for sale. Non-certified wheat may contain restricted noxious weed seed if it is properly labeled (i.e., "Noxious Weed: Wild Oats 4/lb.") showing the species present and the rate of occurrence.

The seed count (if available) is another item to consider. A lower seed count indicates greater seed size, which is correlated with greater yield and better vigor potential. Your seed conditioner can clean and size seed according to requests. For wheat, a slotted screen size of  $\frac{3}{4} \times \frac{3}{4}$  is recommended as it will yield seed counts of approximately 15,000 seeds/lb. Sizing needs will vary each year with variety selection and production environments. Your seed conditioner/cleaner should be able to adjust sizing as needed.

### ***Seeding Rate Calculations***

To calculate actual seeding rates, one needs to know the seed lot purity (% pure seed), germination rate (% germination or % total viable), and the seed count (#/lb.). Seeding recommendations for spring and winter wheat are provided in Chapters 4 and 5. Sample calculations for determining seeding rates are below. Wheat is recommended to be planted at the below rates:

- Firm Seedbed → 28 pure live seeds per square foot  
(approx. 1.22 million pure live seed/acre)
- Soft Seedbed → 32-35 pure live seeds per square foot  
(approx. 1.39 to 1.5 million live seed/acre)
- Late Seeded → 35 pure live seeds per square foot  
(approx. 1.5 million pure live seed /acre)

### ***Calculations***

#### ***Example 1:***

Determine the seeding rate if the goal is 28 pure live seed per square foot seeding density or 1,219,680 pure live seeds per acre. In this calculation, the % pure seed, % germination, and seedcount/lb is 99.5%, 96%, and 13,600 seeds/lb.

$$\text{Seeding Rate (lbs./A)} = \frac{1,219,680 \text{ pure live seeds/A}}{(\% \text{ pure seed}/100) \times (\% \text{ germ}/100) \times (\text{seedcount in \#/lb.})}$$

$$\text{Seeding Rate (lbs./A)} = \frac{1,219,680 \text{ pure live seeds/A} = 93.88 \text{ or } 94 \text{ lbs./A}}{(0.9950) \times (0.96) \times (13,600)}$$

#### ***Example 2:***

Determine the seeding rate if the goal is 1,219,680 pure live seed/a, and the % pure seeds, % germination rate, and seed count in lbs/acre are 99.5%, 85%, and 15,040 seeds/lb.

$$\text{lbs./A} = \frac{1,219,680 \text{ pure live seeds/A} = 95.87 \text{ or } 96 \text{ lbs./A}}{(0.9950) \times (0.85) \times (15,040)}$$

Calculating seeding rates is not hard when you have the necessary information.

### ***Seed diseases***

Two major wheat seed diseases have caused seeding, seedling and production problems: scab (*Fusarium*) and bunt (*Tilletia*). Chapter 23 provides additional information on wheat diseases.

### ***Scab damaged seeds***

Scab-damaged seed is typically lighter in test weight, smaller in size, has lower vigor and carries *Fusarium* spores. Seed wheat which has scab damage should always be rigorously cleaned over a gravity table, and infected seed lots should be treated with a fungicide (prior to planting) to help in seedling emergence and early season (1st month) growth. Fungicides can help increase your germination rates by suppressing/controlling *Fusarium* growth and helping protect seedlings during the early season growth. Planting scabby wheat **does not** mean you will produce scabby wheat as that depends on the environment (amount of rainfall) during wheat flowering.

Visual symptoms of infected seed are not always present on seed or grain, but usually scab-infected wheat kernels are shriveled and discolored with a white, pink, or light brown scaly appearance. These kernels are often referred to as “tombstones.” Infection of scab can also lead to production of mycotoxins in the seed. The most prevalent one, *deoxynivalenol* (also known as DON or by the common name “vomitoxin”), is often tested for as it can cause problems for grain utilization.

Scab-infected seed, if not dead, will have lower vigor and be more susceptible to other field fungi when the seeds germinate in the soil, and plants will remain vulnerable to infections in the seedling stage. In germination testing, infected seeds/seedlings can reduce germination percentages because of primary or secondary infections.

The SDSU Seed Lab has been planting suspect scabby wheat samples in eight replications of 50 seeds to spread out seeds/seedlings in order to reduce secondary infections and provide more accurate results. Normally tests consist of 4 replications of 100 seeds. From past experience, the practice of planting 8 x 50 can increase the rate of normal seedlings (those that have all essential structures for growth) by up to 10 percent.

### ***Bunt***

This is a disease where the inside of the kernel is replaced by black spores, which have a fishy odor when the kernel breaks open. Bunt is usually controlled easily with a fungicide seed treatment. Over the past several years, this disease has shown up again.

### ***Seed Treatment***

An option that growers should always be using is a fungicide seed treatment. Using a seed treatment will not enable germination of dead seed, but it will protect live seeds and seedlings from early season fungal infections. It will also suppress surface-based or endosperm-based *Fusarium* (less severe infections) from growing during the germination test and prevent infection of the seedling, thus allowing that seedling a chance to grow into a productive plant. From past experience, this practice usually increases the rate of normal seedlings (those that have all essential structures for growth) on average by 10 percent or higher. An effective fungicide will normally prevent bunt infection. ***Fungicide seed treatments in wheat are highly recommended, and when used consistently year in and year out, the returns always outweigh the seed treatment costs.***

The SDSU Seed Testing Lab offers a seed treated germination test (using a current and effective fungicide) along with the standard (untreated) germination test to compare potential germination benefits provided by seed treatment. There are several effective fungicides on the market and SDSU does not endorse one over the other. Contact your county Extension educator, your crop consultant, or local cooperative, for treatment products and options.

### ***Seed sources***

Seed quality is crucial and it is recommended that growers purchase seed from reputable producers. Certified seed is highly recommended as it has been field inspected, and lab tested, including a variety identification check in South Dakota. Private companies also sell high quality wheat seed that may or may not be in the Certification program.

Most varieties are protected under the Plant Variety Protection Act (PVP) and can only be sold as a class of certified seed or by the variety owner/developer. “Bin-run” seed is often saved and replanted for one to three years by farmers, depending on the producer’s ability to keep it clean and pure. Bin-run seed should always be cleaned and tested prior to planting.

No one should ever risk planting un-tested seed. Planting bin-run wheat is not a recommended practice, but producers do it to save “seed” money, and will usually re-invest every two to four years in new seed for improved genetics, yield, disease resistance, etc.

If producers raise and sell wheat seed, they need to make sure they follow the laws in doing so. Their best option in South Dakota is to join the South Dakota Seed Certification program and become a Certified Seed Grower.

### ***Seed Testing***

Any of the seed tests mentioned can be performed at the SDSU Seed Testing Lab. A germination or a seed treatment applied germination test is a small price to pay for insuring a good stand. Many producers will request both an untreated germination test and a seed treated germination test on wheat seed. When time is an issue, many producers request the germination assessment potential using the tetrazolium (TZ) test. The TZ test is a biochemical test that can provide estimated germination results in 24 hours. A major drawback with the TZ test on scabby wheat is that it will overestimate (sometimes by 20 percent) the actual germination rate, as TZ does not distinguish scab damage. On non-diseased wheat seed, the TZ test is usually very accurate.

Germination testing takes approximately two weeks on new crop and about one week on old crop. Make sure you mark your sample as new crop or old crop—there is a five-day difference in testing time. New crop must be pre-chilled for five days to break any seed dormancy present. Make sure and ask for a seed count (free with germination test) so you can better calculate planting rates. Seed counts in wheat can range from 10,000 to 26,000 seeds per pound. You do not need to send payment with the sample. The lab bills clients for samples after testing is complete.

Purity analyses and noxious weed seed exams usually only take one to three days to complete once they are received at the Seed Testing Lab. Electrophoresis testing can take up to two weeks.

*Send samples to:*

- SDSU Seed Testing Lab, Box 2207-A, Brookings, SD, 57007 (US Postal Service)  
*or*
- SDSU Seed Testing Lab, 2380 Research Parkway, Brookings, SD 57006 (UPS/FedEx/Speedee)

Please indicate which tests you need, your name and mailing address, telephone number, and your email address if you wish to receive email results (faster turn-around). You can also find us on the Web at <http://www.sdstate.edu/ps/service-labs-orgs/seed-test-lab/index.cfm>.

Seed sample envelopes may be obtained through either the closest Extension office or by contacting the SDSU Seed Testing Lab directly. Growers of certified seed are to use the mailing bag supplied to them after field inspection.

Samples for deoxynivalenol (DON) level tests on grain should be sent to:

- SDSU Plant Diagnostic Clinic, Plant Science, SPB 101, Box: 2108, Brookings, SD 57007. Telephone Number: 605.688.5543

#### **Additional information and references**

*SDSU Seed Testing Lab. Available at [www.sdstate.edu/ps/service-labs-orgs/seed-test-lab/index.cfm](http://www.sdstate.edu/ps/service-labs-orgs/seed-test-lab/index.cfm)*

*SDSU Plant Diagnostic Clinic. Available at <http://www.sdstate.edu/sdces/resources/crops/plant-diagnostic-clinic.cfm>*

*SD Crop Improvement Association. Available at [www.sdstate.edu/ps/sdcia/index.cfm](http://www.sdstate.edu/ps/sdcia/index.cfm)*

*SD Department of Agriculture.*

*Available at [http://sdda.sd.gov/Ag\\_Services/Agronomy\\_Services\\_Programs/Seed\\_Program/default.aspx](http://sdda.sd.gov/Ag_Services/Agronomy_Services_Programs/Seed_Program/default.aspx)*

#### **Acknowledgements**

*Support provided by South Dakota Seed Testing Laboratory.*

---

Turnipseed, Brent. 2012. Wheat seed testing, pure live seed, and seeding rates. *In* Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.







## CHAPTER NINE

# Insuring Wheat in South Dakota

Matthew Diersen ([Matthew.Diersen@sdstate.edu](mailto:Matthew.Diersen@sdstate.edu))

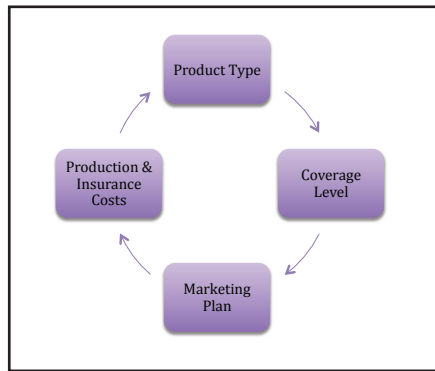
Federal crop insurance protection for wheat production was first provided in 1939. Since then, programs have changed routinely. Changing market conditions, yield performance, and crop mixes make choosing crop insurance an annual exercise. Beginning in the 2011 crop year, many wheat insurance products were grouped together into the Common Crop Insurance Policy. The purpose of this chapter is to highlight the main decisions related to optimal choices of insurance policy type and coverage levels.

### *Managing yield and revenue risks*

Conceptually, producers considering crop insurance enter a decision cycle (Fig. 9.1). Choices are based on risk tolerance, marketing considerations, and price levels. Regardless of where one enters the cycle, revisions are necessary to match insurance needs with costs and marketing considerations. Crop insurance does not substitute for sound marketing and risk management strategies. Insurance only covers downside yield and some price risks. Marketing strategies are necessary to reduce the price risk of selling at a single point in time during the year. In a given year, 30-55% of wheat in South Dakota is marketed after October. Producers should also account for any government programs (such as loan deficiency payments) that would provide income protection under certain circumstances.

The main policy types are *Yield Protection* (YP), *Revenue Protection* (RP), and *Revenue Protection with the Harvest Price Exclusion* (RP-HPE). The optimal coverage level generally refers to the yield coverage level or percent of the producer's actual production history. With YP, a producer would receive an indemnity at the fixed per bushel price if the resulting yield falls below the yield coverage level in a given year. With RP there is a fixed guarantee level and either lower yields and/or lower prices may trigger an indemnity payment.

**Figure 9.1. Crop insurance decisions.**



When selecting insurance coverage, there are two cost categories to consider. The first category is the *overall cost of production* that a producer may seek to insure. Depending on the farm's financial situation and the insurance cost, many producers obtain coverage for seed, chemicals, fuel, and perhaps rent. Under this category, the producer may also wish to provide coverage for the fixed cost of machinery or profits.

The second category is the *cost of the insurance products*. The cost of policy type increases as one moves from yield to revenue protection. Across

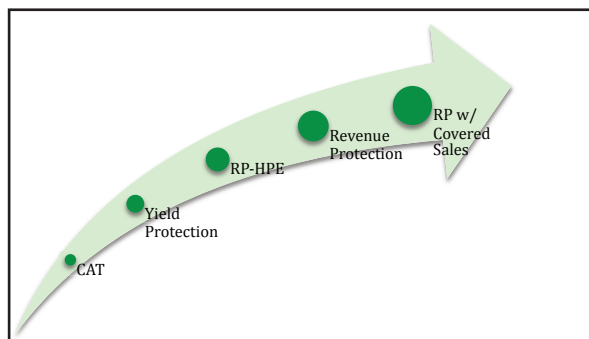
policy types, costs increase with the coverage level. The cost also depends on the crop, the county, and a producer's yield history. The subsidy is substantial and usually means that some level of coverage is economical to purchase regardless of any risk tolerance of the producer.

Price volatility has been high in recent years making insurance coverage more expensive per dollar of coverage purchased. However, the overall dollars or potential loss averted has been higher. In other words, there has been more to lose. Changes in a given year are obscured by changes in the RMA Projected Price and the volatility, both of which drive the premiums.

Proposed insurance decisions can then be weighed against other considerations. What level and under what conditions can some production be prudently hedged? What risks remain? Would unconventional methods be warranted or provide better protection? Eventually the marketing plans are written, the costs to be insured are measured, and the insurance costs are available. Then the final move through the cycle will align the policy type and coverage level with a comprehensive risk management strategy in a cost-effective manner.

Thus, there is a continuum of insurance and marketing choices (Fig. 9.2). Some coverage or use of insurance is expected because of the large subsidy. The subsidy is large enough that minimal insurance will pay for itself over time. Minimal coverage (like catastrophic coverage or CAT) is still available, but has not been widely used in wheat. Relatively high prices reflected in futures prices suggest RP-HPE would be intermediate coverage. It is difficult to justify purchasing YP when RP-HPE is nearly the same cost and provides downside protection. For those forward pricing, standard RP will likely be optimal. The upside protection of RP is often necessary to offset potential hedging losses when yield risk is possible. Given the upside cap on RP, covered sales should be considered if hedging aggressively.

**Figure 9.2. Continuum of insurance and marketing choices.**



At the far extreme are very high coverage levels and full hedging or risk protection. This can be overdone. The subsidy declines as the coverage level increases. In essence, a producer would approach the point where he or she pre-pays the cost of routine yield variability. Over-hedging is another concern as potential hedge losses (usually from extreme price increases) can exceed insurance indemnity levels. Thus, some optimal insurance coverage exists.

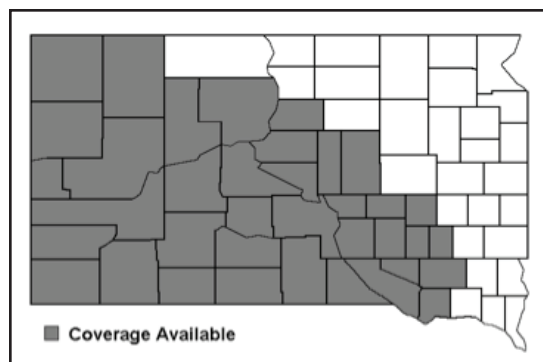
### ***Crop insurance information***

There are several sources of crop insurance information. A crop insurance company or an agent can provide insights and details. A lender may provide a valuable second opinion on the adequacy of coverage based on risk exposure and common practices of other customers. Some commodity brokers are also well versed in the interaction of marketing and insurance tools. The ultimate responsibility, however, remains with the producer.

Wheat coverage details are outlined in the “Common Crop Insurance Policy,” the “Small Grains Crop Provisions,” and the “Commodity Exchange Price Provisions,” or CEPP. Copies are available from crop insurance agents and on the Risk Management Agency (RMA) website ([www.rma.usda.gov](http://www.rma.usda.gov)). Coverage for winter wheat is only available in counties in the southwest two-thirds of South Dakota (Fig. 9.3). In other counties, winter wheat may be covered

by written agreements from insurance companies.

**Figure 9.3. Winter wheat counties of South Dakota.**



Several dates are critical to assure the proper coverage is chosen and in place when needed. The critical dates for winter and spring wheat coverage are dependent on wheat type and location. For *winter wheat*, the sales closing date is September 30, and the final planting date is October 15. The acreage must be reported by November 15. For *spring wheat*, the sales closing date is March 15, and the earliest planting date is either March 16 or March

26 for southern and northern counties, respectively. For spring wheat, the final planting date is May 5 or 15 for southern and northern counties, respectively. Spring wheat acreage must be reported by June 30.

Regardless of the wheat type, after the final planting date there is a 25-day late planting period with reduced coverage levels. The coverage for both types ends on October 31 of the crop year. In the event of a loss, producers have 15 days to make a claim to their insurance agent.

### ***Policy type specifics***

While dates and details are important, the overriding issues that producers struggle with are the choice of policy type and optimal coverage level. Revenue insurance products have dominated wheat coverage in recent years. Relatively high wheat prices have encouraged forward pricing and the use of revenue insurance. In 2011, across spring and winter wheat, over 90% of insured acres in South Dakota were covered by RP. Another 6% of acres were covered by YP. The remaining acres were covered by catastrophic coverage or RP-HPE. Relatively high wheat prices will likely make RP the preferred product.

Winter wheat coverage in South Dakota uses Kansas City Board of Trade (KCBT) contract prices. Under the old policies, winter wheat producers had to consider the harvest price month when making revenue insurance choices. Now there are common projected price discovery and harvest price discovery periods for the policies. The respective harvest periods from an insurance settlement perspective align with the time when historically about 75% of winter and spring wheat is harvested.

For South Dakota winter wheat, the RMA price discovery periods are based on the KCBT September HRW Wheat contract. Spring wheat coverage in South Dakota uses Minneapolis

Grain Exchange (MGE) September HRS Wheat contract prices. The average of the futures closes during the discovery periods sets the respective prices. Discovery periods for spring and winter wheat are summarized in Table 9.1.

**Table 9.1. Discovery periods for the 2012 wheat crop.**

	Projected Price Discovery Period	Harvest Price Discovery Period
Winter Wheat	August 15 to September 14, 2011	July 1 to July 30, 2012
Spring Wheat	February 1 to February 28, 2012	August 1 to August 31, 2012

The RMA Projected Price is used in both YP and RP. Basis is not factored into the RMA Projected Price. As such, the RMA Projected Price will likely be larger than the expected local cash price. The price election level on RP and RP-HPE is fixed at 100%. Producers selecting YP can adjust the price election level below 100% to reduce the cost and level of guarantee if no forward pricing is likely. Historically, there would be a large difference between the yield and revenue insurance price election levels.

RP will increase should the harvest price be higher than the projected price. The 200% limit on the price change by harvest remains in effect. As stated in the CEPP, “The harvest price will not be greater than the projected price multiplied by 2.00,” rewording earlier endorsement limits. Thus, RP is capped once the projected price doubles.

If a producer hedges aggressively, suffers a large yield loss, and the market price increases beyond 200% of the projected price, then hedge losses may exceed indemnity payments. Covered sales seem like the best way to mitigate this low probability event. Forward contract sales or short futures hedges are covered by buying call options on the same number of bushels at a strike price below 200% of projected price.

Producers with RP can select the harvest price exclusion. For most crops, the harvest price exclusion is not expected to be attractive or common. The standard RP is designed to cover price increases and is ideal when producers forward price. Winter wheat is a possible exception. South Dakota winter wheat producers tend to purchase low levels of coverage. They have also stated that higher coverage levels are not cost-effective given the overall profitability of the crop. Given the high yield risk for much of South Dakota, there is also a general reluctance to aggressively forward price winter wheat. RP-HPE may be appealing from the standpoint that it provides downside revenue protection at a slightly higher cost than YP. It also costs less than standard revenue protection, which may not be necessary if little forward pricing is expected.

### ***Coverage level specifics***

Once a policy type has been selected, the coverage level needs to be chosen. With RP there is no price election option; one must use 100% of the projected price (Table 9.2). For YP, a producer can select less than 100% of the projected price. To minimize the insurance premium, a producer could use a price election that closely aligns covered price with the expected cash price. For example, if expected basis is \$0.50 per bushel below an RMA projected price of \$5.00 per bushel, a price election of 90% would match well and reduce the cost of price protection accordingly.

<b>Table 9.2. Summary of insurance options.</b>	
<b>Insurance Option</b>	<b>Detail</b>
<b>Yield Protection (YP)</b>	Price election level can be adjusted to below 100%. The least expensive option but no downside price protection. May be of interest if no forward pricing is likely.
<b>Revenue Protection with Harvest Price Exclusion (RP-HPE)</b>	Price election level fixed at 100%. Slightly higher cost than YP but provides downside price protection. May be of interest if little forward pricing is likely.
<b>Revenue Protection (RP)</b>	Price election level fixed at 100%. Most expensive, but may be best choice if forward pricing. Capped upside protection to offset potential hedging losses when yield risk is possible.

Across policy types the yield coverage level must be chosen. Wheat producers with revenue insurance products used 65% and 70% coverage levels in 2011. The optimal level will depend on a producer's willingness and ability to self-insure the deductible amount and the cost of different coverage levels. The elections range from 50% to 85% coverage for RP and YP. Producers should be able to find a policy that meets their needs. The optimal level is a farm-specific decision and would also be influenced by any forward pricing or protection strategies employed.

### ***Final thoughts***

Insurance is an important part of wheat production in South Dakota. Programs and needs are constantly changing; therefore, it is recommended that coverage be reviewed annually. Producers may want to visit with their agent about how units are treated, prevented planting rules and necessary production records. Producers may also want to visit with their commodity broker about matching marketing to the product type, limiting hedging based on the coverage level, and making covered sales.

Not covered in this publication are: group risk policies (uncommon in South Dakota because of high intra-county yield variability), CAT, durum, unit structure, irrigation, and special issues that arise when both winter and spring wheat are produced and insured on the same farm in a given year.

When a change is made to either insurance or marketing, consider running through the cycle again. When internally consistent, the proper insurance will be in place for the risks faced, hedges will help manage risk, and any worst-case scenarios will have a minimal impact on profitability.

**Additional information and references**

*Risk Management Agency. Available at [www.rma.usda.gov](http://www.rma.usda.gov)*

*Minneapolis Grain Exchange. Available at [www.mgex.com](http://www.mgex.com)*

*Kansas City Board of Trade. Available at [www.kcbt.com](http://www.kcbt.com)*

**Acknowledgements**

*Special thanks to Duane Griffith and Larry Janssen for excellent comments and suggestions.*

---

Diersen, M. 2012. Insuring wheat in South Dakota. *In* Clay, D.E., C.G. Carlson, and K. Dalsted (eds). iGrow Wheat: Best Management Practices for Wheat Production. South Dakota State University, SDSU Extension, Brookings, SD.



## CHAPTER TEN

# Fertilizers Used In Wheat Production

David Clay ([David.Clay@sdstate.edu](mailto:David.Clay@sdstate.edu))

C. Gregg Carlson ([Gregg.Carlson@sdstate.edu](mailto:Gregg.Carlson@sdstate.edu))

In South Dakota, fertilizers are routinely applied to optimize yields. The purpose of this chapter is to discuss the different types of fertilizers that are commercially available.

### Rules of Thumb for Fertilizers

- Match the fertilizer source and application equipment to the problem.
- 1 gallon of 28-0-0 provides approximately 3 lbs of N.
- Follow protocols that minimize losses.
- MAP is often preferred over DAP as a pop-up (placement with the seed) fertilizer.

### Sources

Liquid, solid, and gas fertilizer can be used to return nutrients to the field (Table 10.1) <http://www.tfi.org/factsandstats/fertilizer.cfm>. When selecting the fertilizer, each of these elements should be considered: materials, prices, nutrient concentrations and amounts, potential losses, and special handling requirements. Each type of fertilizer has specific requirements and may require slightly different calculations. For example, liquid and dry fertilizers can be applied to the soil surface while gas fertilizers need to be injected into the soil.

All fertilizers are characterized by their grade. The grade provides information relative to the percentage of N,  $P_2O_5$ , and  $K_2O$  (shorthand for nitrogen, phosphorus and potassium fertilizers) contained in the material (Table 10.1). Liquid fertilizers are also characterized by their density, or concentration (lbs/gal). Different fertilizers are better suited for different applications. For example, liquid urea ammonia nitrate (UAN) is well suited for in-season N application, while anhydrous ammonia is well suited for cultivated land. A rule of thumb for UAN (28-0-0) is that one gallon of fertilizer contains 3 lbs of N. When working with liquid fertilizers, the density is used to convert gallons to lbs or lbs to gallons.



All fertilizers should be applied following protocols that minimize losses. For example, N can be lost through a variety of mechanisms including volatilization, leaching, and denitrification. Volatilization is the gaseous loss of ammonia to the atmosphere which occurs when ammonia-based fertilizers, such as urea, are left on the soil surface. Volatilization losses can be reduced by using a urease inhibitor such as NBPT.

Nitrate leaching is the loss of the negatively charged nitrate ion with percolating water. Nitrate losses can be reduced by splitting the N application or by using a nitrification inhibitor. Nitrate loss is most likely to occur in well drained soils following rainfall. Nitrification inhibitors reduce losses by slowing the rate that the positively charged ammonia ( $\text{NH}_4^+$ ) is converted to the negatively charged nitrate ( $\text{NO}_3^-$ ) ion. Two extensively tested nitrification inhibitors are DCD and nitrapyrin (N-serve®).

## Nitrogen fertilizers

The source of N in most fertilizers is the air. In the manufacturing of N fertilizers, atmospheric N is combined with H from natural gas to form anhydrous ammonia ( $\text{NH}_3$ ), which has a grade of 82-0-0. Producing anhydrous ammonia requires a large amount of energy. For example, the amount of energy required to produce 5 lbs of ammonia fertilizer is approximately equivalent to the energy contained in a gallon of gasoline. Anhydrous ammonia can be used to produce a variety of N products. All ammonia-based products will slowly reduce soil pH.

### *Urea*

Urea is commonly purchased as a solid fertilizer with a grade 46-0-0. To minimize volatilization losses, urea must be incorporated into the soil. Urea is a neutral compound that can be moved into the soil with percolating water. After application, urea is hydrolyzed into ammonia and  $\text{CO}_2$ . This ammonia can be volatilized if the urea is not incorporated. The application of urea with the seed will reduce germination; however, it can be side placed in a band 2 inches to the side and 2 inches below the seed. Additional information on fertilizer placement is available in Jones and Jacobsen (2009). Urea can be blended with MAP or DAP. It should not be blended with superphosphate because it reacts with the superphosphate molecule.

Since urea does not adsorb as much water from the air as ammonium nitrate, it has fewer problems with sticking and caking. Urea should not be mixed with ammonium nitrate because, when mixed together, they absorb atmospheric water and can form a slurry.

[http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/\\$FILE/NSS%20%231%20Urea.pdf](http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/$FILE/NSS%20%231%20Urea.pdf)

### *Ammonium nitrate*

It is the only commonly used solid fertilizer that contains N in the  $\text{NO}_3^-$  form. The chemical formula for ammonium nitrate is  $\text{NH}_4\text{NO}_3$ . Ammonium nitrate is considered to be a hazardous material because of its combustible and explosive properties. If ammonium nitrate comes in contact with oxidizable carbonaceous materials, such as oily substances (petroleum, diesel fuel, herbicides, pesticides, elemental S or powdered metals), they are capable making ammonium nitrate more combustible. If highly contaminated with any of these materials, it can become explosive.

**Table 10.1. Common fertilizers applied to soils in South Dakota.**

	N %	P <sub>2</sub> O <sub>5</sub> %	K <sub>2</sub> O %	Density lbs/gal	S %	Cl %
<b>Solid fertilizers</b>						
Ammonium nitrate	33	0	0			
Diammonium phosphate (DAP)	18-21	46-53	0		1-1.5	
Mono-ammonium phosphate (MAP)	11-13	48-55	0		1-1.5	
Potassium chloride (KCl)	0	0	62			47
Potassium nitrate (KNO <sub>3</sub> )	13	0	44			
Urea (NH <sub>4</sub> ) <sub>2</sub> CO	46	0	0			
<b>Liquid fertilizers</b>						
Urea-ammonium-nitrate (UAN)	28-32	0	0	10.6-11.0		
Ammonium polyphosphate	10	34	0	11.7		
<b>Gas fertilizers</b>						
Anhydrous ammonia	82	0	0			

### ***Anhydrous ammonia***

Anhydrous ammonia (NH<sub>3</sub>) is one of most inexpensive, commercially available N fertilizers. Injection is required for this N source. This product is a flammable and toxic alkaline gas that is stored as a liquefied gas. The fertilizer grade is 82-0-0 and its price is linked to the price of natural gas. In addition to its use as a fertilizer, it is a key ingredient in the illegal production of methamphetamine.

[http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/\\$FILE/NSS%20%2310%20Ammonia.pdf](http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/$FILE/NSS%20%2310%20Ammonia.pdf)

### ***N solutions***

These are liquid fertilizers with grades that range from 28-0-0 to 32-0-0. They are mixtures of urea and ammonium nitrate. Because the solubility of UAN increases with temperature, UAN solutions are made more dilute in regions with cold winter temperatures. These solutions do not have a vapor pressure and can be sprayed or dribbled on the soil surface. 28-0-0 is nonflammable, nontoxic, and therefore is relatively safe and easy to handle, ship, and store. These fertilizers can be corrosive to some metals.

When applied to the soil, volatilization losses can also occur. Volatilization losses will be the most when applied to warm high pH soils. When applied to soils with high residue, some of the N will likely be immobilized in the residue; this can result in yield losses. To reduce these losses, broadcast applications are not recommended in high residue soils. Surface banding, using stream bars, can be used to reduce losses.

[http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/\\$FILE/NSS%207%20Urea%20Ammonium%20Nitrate.pdf](http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/$FILE/NSS%207%20Urea%20Ammonium%20Nitrate.pdf)

### ***Slow release fertilizer***

Slow release fertilizers are one approach for overcoming the need for multiple application dates. In a slow release fertilizer, only a portion of the fertilizer is immediately available. Commercially available products include ureaform (38-0-0) that is a combination of urea with formaldehyde, sulfur-coated urea (36-0-0), and isobutylidene diurea (IBDU).

## **Phosphorus fertilizers**

The production of most commercial phosphate fertilizers begins with the conversion of rock phosphates to phosphoric acid. The phosphoric acid is heated, driving off the water, to produce superphosphoric acid. Ammonia is then added to superphosphoric acid to create the liquid, 10-34-0, which can be mixed with a finely ground potash (0-0-62), water, and urea-ammonium nitrate solution (28-0-0) to form many different grades. When ammonia is added to the phosphoric acid that has not been heated, mono-ammonium phosphate (11-52-0) or di-ammonium phosphate (18-46-0) is produced, depending upon the ratio of the mixture. It is important to consider that P fertilizers are produced from rock phosphate, which is mined. These resources, like oil, are limited. The United States is one of the leading producers of apatite (calcium phosphate minerals).

[http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/\\$FILE/NSS%20%232%20Polyphosphate.pdf](http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/$FILE/NSS%20%232%20Polyphosphate.pdf)

### ***Mono-ammonium phosphate (MAP)***

MAP fertilizer grades range from 11-13% for N and 48-55% for  $P_2O_5$ . In addition, MAP can contain 1 to 1.5% S. The chemical form for MAP is  $(NH_4)H_2PO_4$  and, if pure, it would have a fertilizer grade of 12.2-61.7-0. MAP contains less ammonia than DAP, making it a preferred product to band with seeds.

[http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/\\$FILE/NSS%20%239%20Monoammonium%20Phosphate.pdf](http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/$FILE/NSS%20%239%20Monoammonium%20Phosphate.pdf)

### ***Di-ammonium phosphate (DAP)***

The fertilizer grade of DAP can range from 18-21 for N% and 46-53% for  $P_2O_5$ . The chemical formula for DAP is  $(NH_4)_2HPO_4$  and, if pure, would have a grade of 21.2% N and 53.8%  $P_2O_5$ . DAP can contain 1 to 1.5% S.

### ***10-34-0***

This is a liquid fertilizer that does not require special handling and storage. This fertilizer is corrosive to some metals; therefore, equipment that comes in contact with it must be made of resistant materials. To be kept in a liquid state, it must be stored at a temperature above  $-18^\circ C$ . 10-34-0 is nonflammable, nontoxic, and therefore is relatively safe and easy to handle. 10-34-0 can be sprayed on to the soil surface and incorporated into the soil.

## **Potassium fertilizers**

### ***Potassium chloride***

Potassium chloride (60 to 62%  $K_2O$ ) is often referred to as potash. The color of potash can vary from pink or red to white. White potash is often higher in analysis. One of the advantages of potash is that it often provides chlorine. This material should be stored in a dry location.

### Rules of Thumb for P Fertilizers

- MAP and DAP have very high water solubilities.
- Manure can add a significant amount of P to the soil. Generally P from organic sources is slightly less available when compared to dry or liquid fertilizers. In the year following manure applications, 60 to 80% of the P will be available to the plant.
- Ortho or polyphosphate fertilizers are produced by removing the water from phosphoric acid.
  - The resulting products will contain approximately 40 to 60% orthophosphate with the remaining portion in the polyphosphate form.
  - Examples of fertilizers containing orthophosphates ( $\text{H}_3\text{PO}_4$ ) are MAP and DAP.
  - Polyphosphates have the chemical formula  $\text{H}_4\text{P}_2\text{O}_{10}$ . A fertilizer that contains polyphosphates is 10-34-0.
  - Ortho and polyphosphates are generally considered equally available.

Heat or cold will have little effect on this fertilizer. KCl can be blended safely with both N and P fertilizer to make grades such as 10-30-10, 8-24-24, or 13-13-13. KCl is readily soluble in water and can be applied as a liquid fertilizer.

<http://www.ipni.net/ipniweb/portal.nsf/0/8D207ECED27B691385257713004B611D>

### Potassium sulfate

Potassium sulfate can be used to apply both K and S. The  $\text{K}_2\text{O}$  content of this fertilizer ranges from 48 to 53%, while the S ranges from 17 to 18%. This fertilizer can be applied when additional Cl is undesirable. The salting effect per unit K of  $\text{K}_2\text{SO}_4$  is less than KCl.

[http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/\\$FILE/NSS%205%20Potassium%20Sulfate.pdf](http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/$FILE/NSS%205%20Potassium%20Sulfate.pdf)

### Micronutrients applied to wheat

In addition to N, P, and K, many South Dakota fields also require chlorine and sulfur. Dry fertilizer sources, which include sulfur, include ammonium sulfate (21-0-0-24% S), elemental S (0-0-0-90% S), gypsum (calcium sulfate, 0-0-24), superphosphate (0-20-0, 11-12% S), potassium sulfate (0-0-50-18% S), and di-ammonium phosphate (DAP, 18-46-0, 1-1.5% S) and mono-ammonium phosphate (MAP, 11-48-0, 1-1.5% S).

[http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/\\$FILE/NSS%20%2313%20Sulfur.pdf](http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/$FILE/NSS%20%2313%20Sulfur.pdf)

Two common S containing liquid fertilizers are ammonium polysulfide and ammonium thiosulfate. Ammonium polysulfide is a dark red solution that contains about 20% N and 40% S. It has a density of 9.4 lbs/gal and can be mixed with anhydrous ammonia or ammonia solutions. Ammonium thiosulfate (12-0-0-26% S) has a density of 11.1 lbs/gal and is compatible with aqua ammonia and UAN. This fertilizer should not be placed in contact with a seed or mixed with anhydrous ammonia or phosphoric acid. When this fertilizer is mixed with UAN, the rate that the urea is hydrolyzed ( $\text{urea-N} \rightarrow \text{NH}_4$ ) may be slowed, which in turn can reduce N losses.

[http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/\\$FILE/NSS%20%2308%20Thiosulfate.pdf](http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/$FILE/NSS%20%2308%20Thiosulfate.pdf)

Chlorine can be applied with potassium chloride (0-0-60), which is 47% chloride, ammonium chloride ( $\text{NH}_4\text{Cl}$ ), calcium chloride ( $\text{CaCl}_2$ ), and magnesium chloride ( $\text{MgCl}_2$ ). In many situations, compound fertilizers are applied to soils. These fertilizers can provide both macro- and micronutrients.

[http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/\\$FILE/NSS%234 Compound Fertilizer.pdf](http://www.ipni.net/ipniweb/portal.nsf/0/8d207eced27b691385257713004b611d/$FILE/NSS%234%20Compound%20Fertilizer.pdf)

### ***Potassium chloride (KCl)***

This fertilizer is often called muriate of potash or just potash. The fertilizer provides both K and Cl. Both of these nutrients are needed for wheat health. Potassium chloride is approximately 47% chloride. In wheat,  $\text{Cl}^-$  can help suppress leaf rust. Other fertilizers providing  $\text{Cl}^-$  are ammonium chloride ( $\text{NH}_4\text{Cl}$ ), calcium chloride ( $\text{CaCl}_2$ ), magnesium chloride ( $\text{MgCl}_2$ ), and sodium chloride ( $\text{NaCl}$ ). Potash can be either pink to white. White potash generally has a higher analysis than pink potash.

## **Compound fertilizers**

A compound fertilizer contains multiple nutrients in each granule. These fertilizers differ from blends, where the fertilizers are mixed together. Compound fertilizers are often more expensive than blended fertilizers.

## **Blended fertilizers**

Many custom blends of  $\text{N-P}_2\text{O}_5\text{-K}_2\text{O}$  are available. Common dry blends are 20-10-10, 10-20-20, 8-32-16, and 6-24-24. With dry blended fertilizers, segregation can occur when these materials are transferred from a bin to a truck or a truck to a bin.

## **Manure**

Manure can be used to meet many of the wheat plant nutrient requirements. Mass balance calculations show that manure returns much of the nutrients removed in the harvested grain. Different livestock handling systems are more efficient than others at efficiently returning these nutrients to the soil. Average amounts of N and  $\text{P}_2\text{O}_5$  contained in different manures are shown in Table 10.2.

**Table 10.2. Amounts of N and P<sub>2</sub>O<sub>5</sub> by livestock type (based on Lorimor and Powers 2004).**

Type of livestock	Nitrogen					
	Liquid manure		Solid manure		P <sub>2</sub> O <sub>5</sub>	
	N organic	N inorganic	N organic	N inorganic	Liquid	Solid
	lb N/1000 gal		lbs N/ton		lbs/1000 gal	lbs/ton
Swine						
Farrowing-finish	12	16	8	8	24	7
Nursery	11	14	8	5	19	8
Farrow-feeder	10	11	5	5	18	7
Dairy						
Cow	25	6	8	2	15	3
Heifer	26	6	8	2	14	3
Calf	22	5	8	2	14	3
Herd	25	6	7	2	15	4
Beef						
Beef cow	13	7	4	3	16	4
Feeder calves	19	8	6	3	18	4
Finishing cattle	21	8	7	4	18	7
Poultry						
Broilers	50	13	24	12	40	53
Layers	20	37	22	12	52	51
Tom turkeys	37	16	32	8	40	50
Hen turkeys	40	20	32	8	38	50
Ducks	17	5	13	4	15	21

#### Additional information and references

Clay, D.E., and J.F. Shanahan. 2010. *GIS Applications in Agriculture: Nutrient Management for Improved Energy Efficiency*. CRC Press.

Clay, D.E., N. Kitchen, C.G. Carlson, J.C. Kleinjan and W.A. Tjeutland. 2002. Collecting representative soil samples for N and P fertilizer recommendations. *Crop Management* doi:10.1094/CM-2002-1216-01-MA. Available at <http://www.plantmanagementnetwork.org/cm/>

Clay D.E., S.A. Clay, C.G. Carlson, and S. Murrell. 2010. *Mathematics and Calculations for Agronomists and Soil Scientists*. International Plant Nutrition Institute. Available at <http://ppi-store.stores.yahoo.net/maandcaforag.html>

Engel, R., D. Long, and G. Carlson. 2001. Nitrogen requirement and yield potential of spring wheat as affected by water. *Montana Fertilizing Facts* #25. Available at [http://landresources.montana.edu/fertilizerfacts/25\\_Nitrogen\\_Requirement\\_and\\_Yield\\_Potential\\_of\\_Spring\\_Wheat\\_as\\_Affected\\_by\\_Water.htm](http://landresources.montana.edu/fertilizerfacts/25_Nitrogen_Requirement_and_Yield_Potential_of_Spring_Wheat_as_Affected_by_Water.htm)

Jones, C., and J. Jacobsen. 2009. *Nutrient Management Module No. 11. Fertilizer placement and timing*. Montana State University Extension 4449-11. Available at <http://landresources.montana.edu/nm/Modules/NM11layout.pdf>

Lorimor, J. and W. Powers. 2004. *Manure characteristics*. *Manure Management System Series*. Midwest Plan Service. -18 Sec1, 2nd ed., Ames, IA.

#### Acknowledgements

Support for research activities was provided by South Dakota Corn Utilization Council, South Dakota Soybean Research and Promotion Council, South Dakota Wheat Commission, NASA, South Dakota 2010 Initiative, and North Central SARE program.

---

Clay, D.E., and C.G. Carlson. 2012. Fertilizers used in wheat production. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.





## CHAPTER ELEVEN

# Nitrogen Management for Wheat Production

Ron Gelderman ([Ronald.Gelderman@sdstate.edu](mailto:Ronald.Gelderman@sdstate.edu))

Sang Lee ([Sanghun.Lee@sdstate.edu](mailto:Sanghun.Lee@sdstate.edu))

In many fields, nitrogen (N) is the most limiting nutrient. The purpose of this chapter is to: 1) discuss the N cycle, 2) discuss how N fertilizer impacts wheat yields, 3) provide N fertilizer guidelines to maximize profitability, and 4) provide calculation examples.

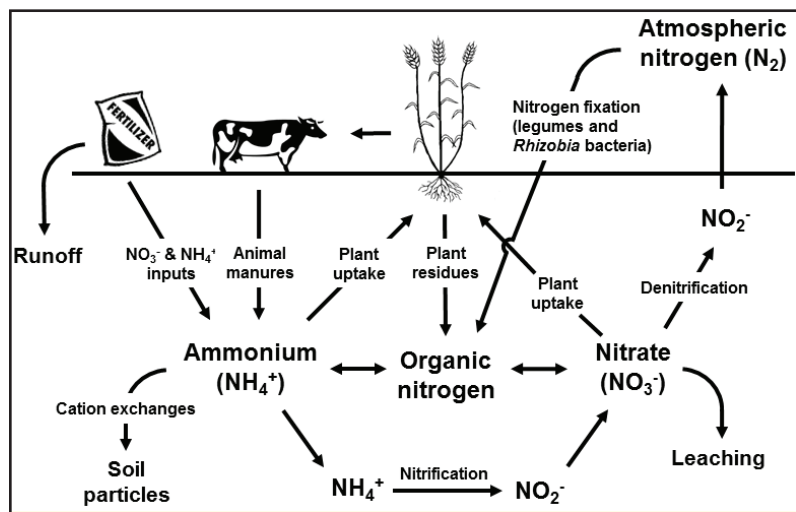


Figure 11.1. A schematic diagram showing nitrogen cycling in agricultural soils. (Source: Sang Lee, SDSU)

### Nitrogen cycle

Nitrogen (N) is present in various forms and passes from the atmosphere to the soil, living organisms, water, and then back into the atmosphere (Fig. 11.1). Industrial and atmospheric fixation processes can convert nitrogen gas ( $N_2$ ) into inorganic N forms such as ammonium ( $NH_4^+$ ) and nitrate ( $NO_3^-$ ), which can be used by wheat. Some legume crops (e.g., alfalfa, clover, peas, and soybeans) in a symbiotic relationship with *Rhizobia* bacteria can also fix  $N_2$  into organic N, which is mineralized by microorganisms.

Soil or fertilizer inorganic N can be lost by leaching and denitrification before being utilized by wheat. For example, in some poorly drained soils, denitrification converts  $NO_3^-$  to nitrous oxide ( $N_2O$ ) or  $N_2$ , which is then lost to the atmosphere. Nitrous oxide ( $N_2O$ ) is a concern because it is a greenhouse gas that traps approximately 298 times more heat than  $CO_2$ . Leaching of  $NO_3^-$  to groundwater is most likely to occur in sandy soils and/or following large rainfalls. Volatilization losses of ammonia gas ( $NH_3$ ) can occur when manure or urea [ $CO(NH_2)_2$ ] is surface applied and not incorporated.

### Nitrogen deficiency

Wheat requires N to produce organic molecules like amino acids, proteins, and nucleic acids. Pale green plants are indicative of N deficiencies (Fig. 11.2). Other symptoms include *chlorosis* (yellowing), which commences on lower leaves beginning at the leaf tips and works inward, reduced tillering, stunting, poor kernel fill, and low grain protein.



**Figure 11.2. Nitrogen deficiency in wheat (N deficient rows on left with N sufficient rows on right).**

(Photo courtesy Jim Shroyer, KSU)

### Nitrogen rates

Nitrogen fertilizer prices have increased in recent years, thus the application of N fertilizer in excess of the plant requirement can decrease producers' potential profit and cause environmental problems. Whereas, applying too little N can reduce yields and wheat quality. Precision N management is necessary, therefore, to increase wheat production efficiency. Nitrogen rate recommendations for South Dakota wheat are based on yield goals, soil testing N levels, and cropping systems. The South Dakota State University (SDSU) current recommendation is 2.5 lbs of N per bushel, which is reduced by accounting for the various credits (Table 11.1). The amount of soil test nitrate-N ( $NO_3^-$ -N), manure N credit, and legume credits (if grown within the previous 2 years) are subtracted from the total N required for yield goals.

<b>Table 11.1. Nitrogen recommendation for wheat in South Dakota.</b> (Gerwing and Gelderman 2005)
<p>N fertilizer recommendation (lbs N/acre) = (2.5 x RYG) - STN - LC - MNC</p> <p>RYG = Realistic yield goal (bu/a)</p> <p>STN = Soil test N value (lb N/a, 2 feet)</p> <p>LC = Legume credit (lb N/a)</p> <p>MNC = Manure N credit (lb N/a)</p>

### ***Soil N credit***

The residual N credit is the amount of  $\text{NO}_3^-$ -N contained in the surface 2 feet (24 inches). Since wheat is a short-season crop, N use by wheat is mainly from available soil N forms and depends less on organic N mineralization when compared to longer season crops such as corn or sunflowers. To determine an accurate soil N credit, the location and number of core samples are important. A general guideline for collecting soil samples is that between 15 to 20 cores should be composited from each uniform area that is sampled. To prevent mineralization (conversion of organic N to  $\text{NH}_4^+$  or  $\text{NO}_3^-$ ) and nitrification (conversion of  $\text{NH}_4^+$  to  $\text{NO}_3^-$ ), which will increase the soil test value, the field samples should be air dried or frozen within 12 hours of sampling. Additional information on methods of soil sampling is available in Gelderman et al. (2005).

### ***Legume credits***

The legume credit accounts for the amount of N that is mineralized from the previous crop. Legumes add N to the soil through symbiotic N fixation. Legume credits used in South Dakota are listed in Table 11.2. When seeding wheat into alfalfa and legume green manure crops using a no-tillage system, a half credit should be used in the current and following year (e.g., 50 lbs at 3-5 plants/sq ft) (Gerwing and Gelderman 2005).

<b>Table 11.2. Legume nitrogen credits for nitrogen recommendations.</b>	
<b>Previous crop</b>	<b>Nitrogen credit (lb/a)</b>
<b>Soybeans, edible beans, peas, lentils and other annual legumes.</b>	<b>40</b>
<b>Alfalfa and legume green manure crop (sweet clover, red clover, etc.)</b>	
<b>Plants/sq ft</b>	
<b>5 and greater</b>	<b>150</b>
<b>3 - 5</b>	<b>100</b>
<b>1 - 2</b>	<b>50</b>
<b>1 or less</b>	<b>0</b>

### ***Manure N credits***

The amount of N available from manure depends on numerous factors including animal age, type of animal, storage characteristics, feed ratios, handling practices, and proposed application procedures. Due to these variations, the most accurate manure N credit is based on actual measured values. Additional background on collecting manure samples for nutrient analysis is available in NRCS (2002), Rieck-Hinz and Richard (2003), and Workman and Shapiro (2009).

Manure analysis should include inorganic (ammonia) and organic N (Gerwing and Gelderman 2005). Credit 35% of the organic N in manure with first-year application, and credit 50% of the organic N if manure had been applied for 2 or more years. Credit 98% of the inorganic N if liquid manure is injected below the soil surface. If manure is broadcast on the surface and incorporated within 24 hours, credit 90% of the inorganic N. When manure is not incorporated until 5 days after application, only 20% of the inorganic N should be used as a credit. If the manure is not sampled, N content estimation procedures are available in Gerwing and Gelderman (2005), Clay and Reitsma (2009) and Chapter 10.

**Table 11.3. Sample N fertilizer calculations.**

Wheat yield goal is 60 bu/a,  
Soil testing N ( $\text{NO}_3\text{-N}$  in 2 feet depth) is 30 lb N/a,  
Previous crop was soybeans,  
Manure N credit (MNC) = 0,  
N fertilizer source is urea with a fertilizer grade of (46-0-0),

Calculation for fertilizer required is:

$$\begin{aligned}\text{N recommendation (lbs/acre)} &= \frac{2.5 \text{ lbs N}}{\text{bu}} \times \frac{60 \text{ bushels}}{\text{acre}} - \text{STN} - \text{LC} - \text{MNC} \\ \text{STN} &= \frac{30 \text{ lbs}}{\text{acre}}; \text{LC} = \frac{40 \text{ lbs}}{\text{acre}}; \text{MNC} = \frac{0 \text{ lbs}}{\text{acre}} \\ \text{N recommendation} &= \frac{150 \text{ lbs N}}{\text{acre}} - \frac{30 \text{ lbs } \text{NO}_3\text{-N}}{\text{acre}} - \frac{40 \text{ lbs}}{\text{acre}} - \frac{0 \text{ lbs}}{\text{acre}} = \frac{80 \text{ lbs N}}{\text{acre}} \\ \text{Urea (46\% N) required} &= \frac{80 \text{ lbs N}}{\text{acre}} \times \frac{1 \text{ lb urea}}{0.46 \text{ lbs N}} = \frac{174 \text{ lb urea}}{\text{acre}}\end{aligned}$$

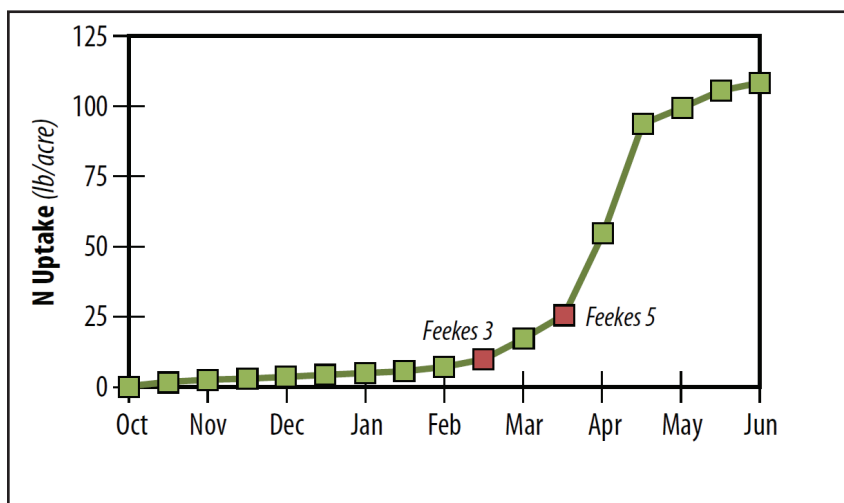
### ***Calculating the N recommendation***

Once the yield goal and all credits (soil N credit, manure N credit, and legume credit) are determined, the N fertilizer recommendation can be calculated. An example calculation for N recommendation is shown in Table 11.3.

### ***N materials, timing and placement***

An N fertilizer program must consider the N source, timing, rate, and placement (Fig. 11.3, Table 11.4). The two nitrogen materials most commonly used in South Dakota wheat production are dry urea (46-0-0) and liquid urea ammonium nitrate (UAN). The UAN can vary from 28 to 32% N and consists of  $\frac{1}{2}$  urea,  $\frac{1}{4}$  ammonium and  $\frac{1}{4}$  nitrate-N. The density of UAN (28-0-0) is approximately 10.6 lbs/gal, thus one gallon of 28% UAN contains approximately 3 lbs of N.

The proper timing of N fertilizer is necessary for wheat production because the plants' demand for N is tied to its growth stage (see Chapter 3 for more details on growth stages). Winter wheat requires relatively low N amounts in the fall, while N uptake increases rapidly when wheat starts growing rapidly (Feekes 4-5) in the spring (Fig. 11.3). To meet this need, two N application options (a single application or a split application of N fertilizer) can be used. The first application can be made at planting, while the second should be applied prior to jointing or stem elongation (Feekes 4-5). It needs to be pointed out that N fertilizer should not be applied over snow.



**Figure 11.3. Nitrogen uptake by winter wheat over the growing season.**  
(Courtesy Murdock et al. UKY)

For spring wheat, a similar approach can be followed, with a portion applied at planting and the remainder applied between V5 and jointing (Feekes 4-5) (Table 11.4). N applied too early can increase lodging and excessive tillering, while N applied too late can result in lower yields (Glover and Hall 2006; Ibrahim et al. 2006; Otteson et al 2007). Late season N applications do not impact yield and may only increase protein. Generally, below ground N bands are more effective than surface applications. Nitrogen placement and timing options are provided in Table 11.5.

Table 11.4. Nitrogen timing influence on spring wheat yield near Brookings, SD.			
Nitrogen Timing <sup>1</sup>	N rate	Yield	Yield Increase
	lb/a	----- bu/a -----	
Check	0	47	0
Planting	50	70	23
Tillering	50	70	23
Jointing	50	65	18
Boot	50	59	12
Heading	50	48	1

<sup>1</sup> 28 lb N/a, 2 feet nitrate soil test, broadcast ammonium nitrate.

### Summary

In-season N application on grain yields and grain quality are dependent on seasonal and site-specific environmental and wheat growth conditions. The time window for applying in-season N for wheat post-plant is relatively short. If N is delayed until after tillering, the window can be only 1-2 weeks long. Relying on in-season N contains risk because: 1) wet conditions can prevent a timely application of the fertilizer, and 2) once the fertilizer is applied, rainfall is required to transport the N into the soil where it can be used by the plant.

The pre-plant N recommendations for spring wheat are dependent on many factors including soil texture, soil test N, labor and equipment needs, and variety (some varieties are very susceptible to lodging). If excellent growing conditions exist (good stands, tillering and soil moisture) before jointing and if it appears that actual yield could exceed yield goal, an in-season addition of 25 to 50 lbs of N can be considered. The market basis for high-protein wheat will also warrant consideration of in-season N applications. Application of N for winter wheat is usually made in the spring soon after greenup.

Table 11.5. Nitrogen management options for winter and spring wheat.		
Season	Time of N application	N placement options.
Fall	Post-plant winter wheat	Delay until soil temperature < 50 °F. Avoid UAN, if leaching is possibility. Subsurface applications are more efficient.
Winter	Post-plant winter wheat	Avoid on sloping, frozen soils. Avoid application on snow-covered soils.
Early-mid spring	Winter wheat-post	Subsurface applications or incorporation are more efficient.
	Spring wheat-preplant/plant	Less volatilization losses when surface applied now (<60 °F temps) compared to later in spring.
Late spring	Post-plant	UAN banded is preferred over urea if surface applied. Consider urease inhibitor or poly-coated urea if surface applied.

## Additional information and references

State	Fertilizer recommendations	Website
Nebraska	Fertilizer recommendations	<a href="http://cropwatch.unl.edu/web/wheat/soils">http://cropwatch.unl.edu/web/wheat/soils</a>
North Dakota	Fertilizer recommendations	<a href="http://www.ndsu.edu/fileadmin/soils/pdfs/sf882.pdf">http://www.ndsu.edu/fileadmin/soils/pdfs/sf882.pdf</a>
Montana	Micro-nutrients	<a href="http://landresources.montana.edu/nm/Modules/Module7.pdf">http://landresources.montana.edu/nm/Modules/Module7.pdf</a>
Montana	N recommendation	<a href="http://landresources.montana.edu/nm/Modules/NM%203%20mt44493.pdf">http://landresources.montana.edu/nm/Modules/NM%203%20mt44493.pdf</a>
Wyoming	Recommendation	<a href="http://uwadmnweb.uwyo.edu/soilfert/Pubs/Blaylock_etal_1996.pdf">http://uwadmnweb.uwyo.edu/soilfert/Pubs/Blaylock_etal_1996.pdf</a>

Clay, D.E., and K.D. Reitsma. 2009. Soil fertility. In Clay, D.E., K.D. Reitsma, and S.A. Clay (eds). *Best Management Practices for Corn Production in South Dakota*. EC929. South Dakota State University, SDSU Extension, Brookings, SD. Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/EC929.07.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC929.07.pdf)

Gelderman R., J. Gerwing, and K. Reitsma. 2005. Recommended soil sampling methods for South Dakota. FS 935. College of Agriculture and Biological Sciences, South Dakota State University, SDSU Extension, South Dakota Department of Agriculture, Brookings. Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/FS935.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/FS935.pdf)

Gerwing, J., and R. Gelderman. 2005. Fertilizer recommendations guide. EC750. South Dakota State University, SDSU Extension, United States Department of Agriculture. Brookings, SD. Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/EC750.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC750.pdf)

Glover, K., and R.G. Hall. 2006. Traverse: A new high yielding and fusarium head blight tolerant spring wheat. B749. South Dakota State University, Agricultural Experiment Station, USDA. Available at <http://www.sdwheat2.org/files/TraverseB749.pdf>

Ibrahim, A., T. Nleya, and J. Rickertsen. 2006. Alice: A high yielding hard white winter wheat. B753. South Dakota State University, Agricultural Experiment Station, USDA. Available at <http://www.sdwheat2.org/files/Alice.pdf>

Murdock, L., J. Grove, and G. Schwab. 1995. Fertilizer management. In Lee, C., and J. Herbek (eds). *A Comprehensive Guide to Wheat Management in Kentucky*. University of Kentucky, Cooperative Extension Service, Lexington, KY. Available at <http://www.uky.edu/Ag/GrainCrops/ID125Section5.html>

NRCS. 2002. Sampling manure for nutrient management. SD-NRCS-FS-36. Available at <ftp://ftp-fc.sc.egov.usda.gov/SD/www/News/FactSheets/sampling.pdf>

Otteson, B.N., M. Mergoum, and J.K. Ransom. 2007. Seeding rate and nitrogen management effects on spring wheat yield and yield components. *Agron. J.* 99:1615-1621.

Rieck-Hinz, A., and T.L. Richard. 2003. How to sample manure for nutrient analysis. PM 1558. Iowa State University Extension. Available at <http://www.extension.iastate.edu/Publications/PM1558.pdf>

Workmann, C.S., and C.A. Shapiro. 2009. Sampling manures for nutrient analysis. G1450. University of Nebraska–Lincoln Extension, Institute of Agriculture and Natural Resources, Lincoln, NE. Available at <http://elkhorn.unl.edu/public/live/g1450/build/g1450.pdf>

## Acknowledgements

Support for this chapter was provided by South Dakota State University, South Dakota Wheat Commission, and South Dakota Soybean Research and Promotion Council.

Gelderman, R., and S. Lee. 2012. Nitrogen management for wheat production. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.







## CHAPTER TWELVE

# Estimating Nutrient Removal in Wheat Grain and Straw

David Clay ([David.Clay@sdstate.edu](mailto:David.Clay@sdstate.edu))

C. Gregg Carlson ([Gregg.Carlson@sdstate.edu](mailto:Gregg.Carlson@sdstate.edu))

The mining of soil nutrients (soil organic C, N, P, K, Cl, and S) constitutes a grave concern for the long-term sustainability of South Dakota soils. This section provides examples that demonstrate how to calculate the amount of nutrients removed (on a per unit basis) in wheat grain and straw. While N losses will be illustrated, other nutrient losses can be estimated using these techniques.

Crop removal can be estimated based on data provided in Table 12.1. Mining is the difference between nutrient applied and crop removal. If the removal rate exceeds the application rate, then the soil nutrient is being mined. The extent of soil mining can be estimated by subtracting the nutrients removed in the grain and straw from the amount of fertilizer applied (Table 12.3).

**Table 12.1. Nutrients contained in wheat grain and straw.**  
<http://ppi-store.stores.yahoo.net/maandcaforag.html>

Measurement		Removal/		Unit (lbs/unit)			
	Unit	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Mg	S	Cl <sup>-</sup>
Wheat grain	Bu	1.5	0.6	0.34	0.15	0.1	0.026
Wheat straw	Bu	0.7	0.16	1.2	0.1	0.14	ND
Wheat straw	Ton	14	3.3	24	2	2.8	

Nutrients are removed from the ‘soil bank’ every time grain or straw is removed from the field (Tables 12.1 and 12.2). Harvesting both grain and residue will remove more nutrients than the grain alone. The amount of straw contained in a field can be estimated with the harvest index, which is the ratio of grain divided by grain plus straw.

**Table 12.2. Estimating N removal rates.**

Removal = Yield • nutrient content/unit measure

*N in grain*

If 1 bushel wheat contains 1.5 lbs of N, how much N is removed in 40 bu (at 13.5% moisture)?

$$\frac{40 \text{ bushels}}{\text{acre}} \cdot \frac{1.5 \text{ lbs}}{1 \text{ bushel}} = 60 \text{ lbs/acre}$$

*N in straw*

If 1 lb of dry (0% moisture) grain produces 1.35 lbs of dry straw, and 1 bushel of wheat at 13.5% and 0% moisture, they would weigh 60 and 51.9 lbs each.

$$\frac{40 \text{ bushels}}{\text{acre}} \cdot \frac{51.9 \text{ dry lb wheat}}{1 \text{ bu}} \cdot \frac{1.35 \text{ lb straw}}{1 \text{ lbs dry wheat}} \cdot \frac{\text{ton}}{2000 \text{ lbs}} \cdot \frac{14 \text{ lb N}}{\text{ton}} = 19.6 \text{ lb N/acre}$$

*Total N removed in grain plus straw*

$$60 \text{ lb N/a} + 19.6 \text{ lb N/a} = 79.6 \text{ lb N/acre}$$

**Table 12.3. Calculating N mining amounts.**

Mined N = N added – N removed

Based on Table 12.2, N removal is 79.6 lbN/acre

N added is 100 lb/acre of urea

N in urea is  $100 \times 0.46 \text{ lb N/lb urea} = 46 \text{ lbs N/acre}$

Mined N =  $46 - 79.6 = -33.6 \text{ lbs N/acre}$ . Based on this calculation, 34 lbs is being mined from the soil annually.

Generally, wheat produces (on a dry weight basis) 1.3 to 1.4 lbs straw per 1 lb dry grain. Sample removal rate calculations are in Table 12.2. Additional information is available at:

<http://www.back-to-basics.net/assets/agribriefs/Winter2003-2.pdf>

[http://njveg.rutgers.edu/assets/pdfs/soil/fs014-jhNutrient\\_Removal\\_Values\\_for\\_Field\\_and\\_Forage\\_Crops.FS014.pdf](http://njveg.rutgers.edu/assets/pdfs/soil/fs014-jhNutrient_Removal_Values_for_Field_and_Forage_Crops.FS014.pdf)

For a complete nutrient balance, the entire rotation as well as the fertilizers and manures added to the system must be considered.

#### Additional information and references

Clay, D.E., S.A. Clay, C.G. Carlson, and S. Murrell. 2010. *Mathematics and Calculations for Agronomists and Soil Scientists*. International Plant Nutrition Institute. Available at <http://ppi-store.stores.yahoo.net/maandcaforag.html>.

#### Acknowledgements

Support for this chapter was provided by South Dakota State University, South Dakota Corn Utilization Council, USDA-NIFA South Dakota 2010 research program, South Dakota Wheat Commission, and South Dakota Soybean Board.

---

Clay, D.E., and C.G. Carlson. 2012. Estimating nutrient removal in wheat grain and straw. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.





## CHAPTER THIRTEEN

# Phosphorus, Potassium, Sulfur, and Chloride Requirements

Ron Gelderman ([Ronald.Gelderman@sdstate.edu](mailto:Ronald.Gelderman@sdstate.edu))

Sang Lee ([Sanghun.Lee@sdstate.edu](mailto:Sanghun.Lee@sdstate.edu))

In South Dakota wheat yields can be limited by phosphorus, potassium, sulfur, and chloride. The purpose of this chapter is to provide an overview of each nutrient as well as provide guidance on how to reduce yield losses due to these nutrient deficiencies.

### **Phosphorus**

Phosphorus is required for root development, tillering, winter survival, and grain filling. If the soil does not contain an adequate amount of P, deficiencies can reduce yields 50% or more. Three basic approaches can be used to minimize P deficiencies.

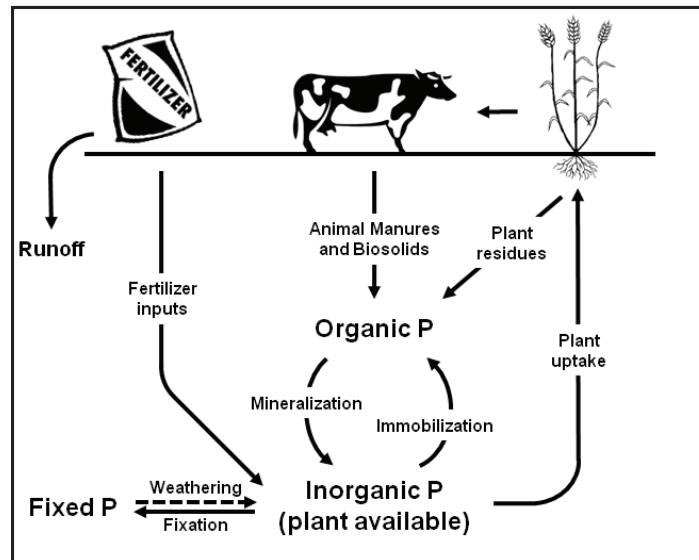
The first approach relies on *rotations* to increase mycorrhizae populations. These fungi can increase P uptake efficiency by increasing the effective length of the root system. The importance of these organisms is discussed in Chapter 17.

The second approach relies on *mass balance calculations* where soil nutrient mining is estimated (Chapter 12). In this approach, inputs are compared with outputs. For P, outputs consist of the P removed in the harvested grain and straw. For example, a bushel of wheat and ton of wheat straw contains approximately 0.60 and 3.3 lbs of  $P_2O_5$ , respectively (Clay et al. 2010), whereas inputs are the P contained in manure and fertilizer. Examples for calculating a mass balance are provided in Chapter 12 and information on commonly used fertilizers is provided in Chapter 10.

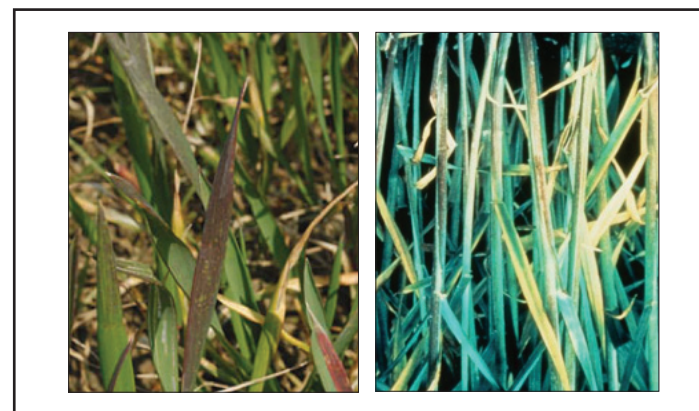
Common P fertilizers used in South Dakota are di-ammonium phosphate (DAP, 18-46-0), mono-ammonium phosphate (MAP, 11-52-0), and ammonium polyphosphate (10-34-0, 11.7 lbs/gal). DAP and MAP are solid fertilizers, while ammonium polyphosphate is a liquid fertilizer. If manure is applied, the analyzed manure P content is estimated as 90 to 100% plant available.

The third approach relies on *soil sampling* to determine the fertilizer recommendation. Soils contain P in several different forms (Fig 13.1). Approximately 1% of the total soil P is in a plant-available form with the remainder as inorganic P (mineral or absorbed on clay surfaces), or tied up in crop residues and/or organic matter. Both inorganic and organic P forms can be converted to plant-available forms through chemical/physical or microbiological processes. No matter which approach is used, soil sampling should be used to track changes in soil nutrient bioavailability.

**Figure 13.1. Phosphorus cycle in agricultural soils.** (Source: Sang Lee, SDSU)



**Figure 13.2. Phosphorus deficiency in wheat.**  
(Source: <http://www.croptcare.com/whycroptcare.html> and <http://www.smallgrains.org>)



### ***P deficiency symptoms***

In plants, P is considered a mobile nutrient and, therefore, deficiencies are generally observed in lower leaves. The most common symptoms are purpling or the development of a light green color (Fig. 13.2). In some situations, P deficiencies can be confused with N deficiencies. Other symptoms include reduced tillering and growth and overall non-vigorous plant growth. Phosphorus soil test summaries for South Dakota reveal that about 2/3 of the state's soils require additional P for adequate wheat growth (Gelderman and Ulvestad 2009).

### Soil-based P recommendations

South Dakota phosphorus fertilizer recommendations are based on the soil test P level and wheat yield goal (Table 13.1). Three different extractants, *Olsen*, *Bray-1* or *Mehlich III*, can be effectively used to determine soil test P levels in the top 6 inches of soil (Gerwing and Gelderman 2005). The Bray-1 and Mehlich III methods are typically used in acid soils (pH less than 7), while the Olsen P method can be used for both low and high pH soils. The Bray-1 method is not recommended for basic (pH greater than 7) soils because this method underestimates plant available P.

An additional test, the Bray P-2 test, has not been adequately correlated to wheat's response to P fertilizer in South Dakota. The soil test results represent index values that coincide with relative yield increases to added P. The critical level for South Dakota wheat is 16 ppm (Olsen method). Research conducted at 33 sites in South Dakota shows that P fertilizer application increased yield by 36% in the very low soil test P level (0-3 ppm) soils. In soils with high (12-15 ppm) to very high P (>16 ppm), responses are less likely.

For soil test P recommendations, soil samples from the surface 6 inches should be collected. A composite sample from a field should contain at least 15 to 20 individual cores. It is recommended that sampling should not include cores from waterways, terraces, and other unusual areas or from old homesteads, feedlots or fencerows. More specific sampling suggestions can be found online at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/FS935.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/FS935.pdf) and also available in Clay et al. (2002).

### Applying P

Time of P application is not critical as long as the recommended P rate is applied before crop uptake. Applying recommended P for two crop years has also been shown to be an effective practice. Banding with or near the seed is considered the most efficient approach to apply P. Compared to broadcast applications, similar yield responses can be

**Table 13.1. Sample P fertilizer calculations for wheat.**

#### **OLSON P METHOD**

$$\frac{\text{Recommended } P_2O_5}{\text{acre}} = [1.071 - (0.067 \times \text{STP})] \times \text{RYG}$$

Where :

STP is the soil test value in ppm, and RYG is the realistic yield goal in bu per acre.

Example, Soil test P = 8 ppm, the yield goal is  $\frac{60 \text{ bu}}{\text{acre}}$ , and MAP (11-52-0) is the P source

$$\frac{\text{Recommended } P_2O_5}{\text{acre}} = [1.071 - (0.067 \times 8)] \times 60 = \frac{32 \text{ lbs } P_2O_5}{\text{acre}}$$

$$\frac{32 \text{ lbs } P_2O_5}{\text{acre}} \times \frac{1 \text{ lb MAP}}{0.52 \text{ lbs } P_2O_5} = \frac{62 \text{ lbs MAP}}{\text{acre}}$$

#### **BRAY-1 P METHOD AND MEHLICH III METHOD**

$$\frac{\text{Recommended } P_2O_5}{\text{acre}} = [1.071 - (0.054 \times \text{STP})] \times \text{RYG}$$

Example, Soil test P = 8 ppm, and the yield goal is  $\frac{60 \text{ bu}}{\text{acre}}$ , and DAP (18-48-0) is the P source

$$\frac{\text{Recommended } P_2O_5}{\text{acre}} = [1.071 - (0.054 \times 8)] \times 60 = \frac{38 \text{ lbs } P_2O_5}{\text{acre}}$$

$$\frac{38 \text{ lbs } P_2O_5}{\text{acre}} \times \frac{1 \text{ lb DAP}}{0.48 \text{ lbs } P_2O_5} = \frac{79 \text{ lbs DAP}}{\text{acre}}$$



obtained with  $\frac{1}{3}$  less P when band applied. However, reducing the P rate can result in a gradual decrease in the soil test P level. Banding too much fertilizer with the seed can cause seed or seedling injury from fertilizer salts and decrease seed germination.

A spreadsheet by Gelderman (2009) can be used to estimate maximum amounts of common fertilizers that can be applied with wheat at seeding.

<http://www.sdstate.edu/ps/service-labs-orgs/soil-test-lab/loader.cfm?csModule=security/getfile&PageID=788496>

### ***Phosphorus in the environment***

Phosphorus is a non-mobile soil nutrient. This means that as a soil nutrient, it generally does not leach to the groundwater. Although P is an essential nutrient for wheat, surface runoff from fields can contain P, which can have detrimental effects on water quality (e.g., eutrophication) in lakes and streams. Phosphorus losses from fields are primarily influenced by soil erosion, P content in the soil, the application method for fertilizer or the type of manure used for P sources. Tillage methods and cover crops can play an essential role in limiting soil erosion and thus inhibiting P movement to water bodies. Lower soil P values and subsurface P placement will also limit soluble P movement.

To limit P movement/loss via surface water, either inject P, till into soil or utilize band placement. Manure should be tilled in or injected, but not applied to frozen or snow-covered soils. Phosphorus in soils is attached to soil particles and contained in organic matter. When soil particles are carried to lakes or streams, P can be released into the water. Cropping systems that reduce soil erosion will also reduce P loss. Therefore, the use of conservation tillage or no-tillage can be expected to reduce total P loss. Ground cover is essential to limit erosion, and planting of cover crops after wheat can also reduce P loss. Vegetative filter strips on hillsides and well-placed vegetative buffer zones along streams can be effective in filtering out sediments and some nutrients before they enter surface waters.

### ***Potassium***

Plants require potassium (K) for protein synthesis and photosynthesis. Most agricultural soils in South Dakota have relatively high K levels. However, soils in northeast South Dakota are relatively low in this element.

Potassium deficiency in wheat appears on the lower leaves as necrosis on the tip and edges and developing toward the leaf base (Fig. 13.3). Death of older leaves occurs more rapidly than leaves with N deficiency, and plants may appear to be suffering from drought stress. Only 0.34 lb  $K_2O$  is removed with a bushel of wheat; baling of the straw will, however, remove another 1.2 lb  $K_2O$ /bu (Clay et al. 2010). Approximately 3.3 lbs  $K_2O$  are contained in each ton of wheat straw.

### ***Soil test K***

Potassium levels in soil are measured with the ammonium acetate test on a 0-6 inch depth soil sample (Gerwing and Gelderman 2005). The critical level for South Dakota wheat is 160 ppm K. Potassium fertilizer recommendations for wheat are based on the soil K test and the yield goal (Table 13.2).

### ***Applying K***

Potassium chloride (0-0-60) is the primary K fertilizer available in South Dakota. Low soil temperature and high clay content can decrease K availability. Banding K is an effective

application method; K starter banding has shown increases in K efficiency in Montana soils (Korb et al. 2005). Although higher rates of 0-0-60 can safely be banded with the seed (Gelderman 2009), it is usually not practical to do so. Application rates above 20-30 lbs K<sub>2</sub>O/a should be broadcast.



**Figure 13.3. Potassium deficiency symptom.** (Source: CIMMYT)

**Table 13.2. Potassium fertilizer recommendation.** (Gerwing and Gelderman 2005)

$$\frac{\text{Recommended K}_2\text{O}}{\text{acre}} = [2.71 - (0.017 \times \text{STK})] \times \text{RYG}$$

Where:

STK is the soil test K value in ppm, and RYG is the realistic yield goal in bu per acre.

Example, Soil test K = 100 ppm, and the yield goal is  $\frac{60 \text{ bu}}{\text{acre}}$

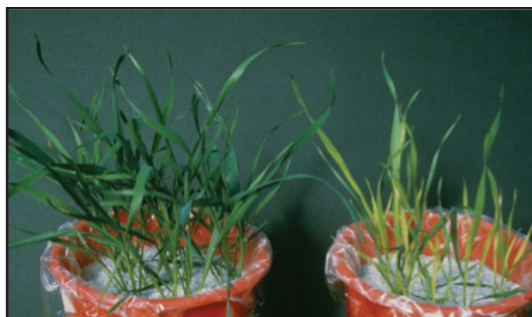
$$\frac{\text{Recommended K}_2\text{O}}{\text{acre}} = [2.71 - (0.017 \times 100)] \times 60 = \frac{61 \text{ lbs K}_2\text{O}}{\text{acre}}$$

### ***Sulfur***

Wheat requires sulfur (S) to synthesize proteins that impact grain quality. In the past, atmospheric deposition of S provided much of the plant's requirement. However, air quality improvements have reduced S depositions, which have contributed to S deficiencies. In addition, less tillage (less organic matter mineralization) and higher yields (more S removal) also have led to more S deficiencies.

Sulfur deficiencies are similar to nitrogen deficiencies in that the leaves appear yellow (Fig. 13.4). These deficiencies should not be confused with herbicide injury, which also can cause chlorotic symptoms. Unlike N, S deficiency appears first on younger leaves because S is not as mobile in the plant as N. Sulfur deficiency in wheat is difficult to diagnose in the field and thus, plant or soil analysis should be used to verify the diagnosis.

Sulfur deficiency is more common in: 1) wheat grown using no-tillage, and 2) wheat grown on coarse-textured soils low in organic matter. Often S deficiency is found on the more eroded parts of the landscape (side hills), while the lower areas of the field are unaffected.



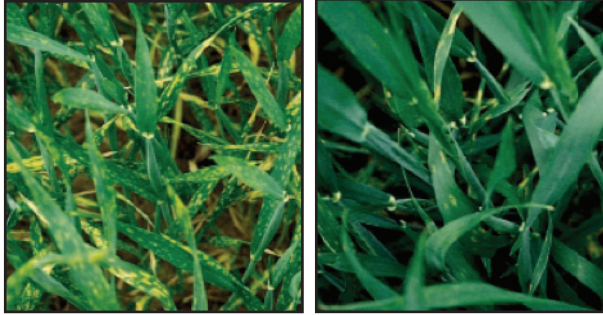
**Figure 13.4.** Sulfur deficiency symptom (right) compared to healthy wheat (left). (Source: CIMMYT)

Table 13.3. Sulfate recommendations for South Dakota wheat. (Gerwing and Gelderman 2005)					
Sulfate soil value (based on a 2-foot sample)	Relative level	Soil Texture			
		Coarse		Medium/Fine	
		Tilled	Strip-till or no-till	Tilled	Strip-till or no-till
Lbs SO <sub>4</sub> -S/acre		lb S/a			
0 – 9	Very low	25	25	25	25
10 – 19	Low	25	25	15	25
20 – 29	Medium	15	25	0	15
30 – 39	High	15	15	0	15
≥ 40	Very high	0	0	0	0

The recommended S rate is based on the soil test, texture, and tillage systems (Table 13.3). Since the sulfate ion is somewhat mobile in soils, soil should be sampled to 2 feet. Sulphur is not subject to volatilization; therefore, surface applications can be used. Commonly used S fertilizers are ammonium sulfate (21-0-0-24 S), ammonium thiosulfate (26% S, 11.4 lb/gal), gypsum (18% S), and potassium sulfate (17% S). If band applied near the seed, avoid using ammonium thiosulfate. Dry sulfur fertilizer materials can be applied with the seed at rates of 10-15 lb S/a. Elemental sulfur should be applied well before wheat is planted because the material requires 1 to 3 months in warm soil before it is completely available to be absorbed by plants. The P fertilizers MAP and DAP may also contain 1-1.5% S (Chapter 10).

### **Chloride**

Chloride (Cl) is a critical component in the opening and closing of stomata and in photosynthesis. Leaf spotting is a deficiency symptom in wheat (Fig. 13.5) that can appear with very low soil chloride levels. Although Cl<sup>-</sup> is a required nutrient, it is needed in very small amounts. Deficiencies have been shown to limit wheat growth in South Dakota. In Cl<sup>-</sup> deficient soils, fertilizer applications can increase yields up to 15 bu/a.



**Figure 13.5. Chloride deficiency (spotting) symptom (left) compared to healthy plant (right, with 24 lb Cl/a).** (Source: International Plant Nutrition Institute)

Chloride response has been related to a pre-plant soil Cl test (Table 13.4). South Dakota studies have shown a high probability of yield response from Cl fertilization when the soil test level is below 30 lb Cl/a. Little yield response was observed when it exceeds 60 lbs/a. In many fields, the response is due to the suppression of leaf disease. Chloride application rates are determined by subtracting the chloride soil test level (from the top 2 feet of soil) from 60 lbs/a, with a minimum recommendation of 15 lbs Cl/a (Table 13.5).

In general, fields that are poorly drained or have had a recent history of manure application, irrigation and/or potash (KCl) fertilization will have adequate soil chloride levels. Some recent research indicates that Cl may be cultivar-dependent. Chloride is most economically applied as potash, KCl (0-0-60), and should be surface broadcast.

Table 13.4. South Dakota soil test Cl recommendations. (Gerwing and Gelderman 2005)	
Chloride soil value	Relative level
Lbs Cl/acre	
0 - 15	Very Low
16 -30	Low
31 - 45	Medium
46 - 60	High
60	Very High

Table 13.5. Sample calculation for Cl fertilizer recommendations.
Determine Cl in soil
$3 \text{ ppm} = \frac{3 \text{ lb Cl}}{10^6 \text{ lb soil}} \text{ so } \frac{3 \text{ lb Cl}}{10^6 \text{ lb soil}} * \frac{2 * 10^6 \text{ lb soil}}{\text{Acre 6 lb soil}} = \frac{6 \text{ lb Cl}}{\text{Acre 6 inch soil}}$
$\frac{4 \text{ lb Cl}}{10^6 \text{ lb soil}} * \frac{6 * 10^6 \text{ lb soil}}{\text{Acre 18 inch soil}} = \frac{24 \text{ lb Cl}}{\text{Acre 18 inch soil}} \text{ and } \frac{6 \text{ lb Cl}}{\text{Acre 6 inch soil}} + \frac{24 \text{ lb Cl}}{\text{Acre 18 inch soil}} = \frac{30 \text{ lb Cl}}{\text{Acre 24 inch soil}}$
Assume that threshold is 60 lb Cl, then determine needed Cl
$\frac{60 \text{ lb Cl}}{\text{Acre 24 inch soil}} - \frac{30 \text{ lb Cl}}{\text{Acre 24 inch soil}} = \frac{30 \text{ lb Cl}}{\text{Acre 24 inch soil}} \text{ Then determine KCl recommendation}$
$\frac{30 \text{ lb Cl}}{\text{Acre 24 inch soil}} * \frac{1 \text{ lb KCl}}{0.47 \text{ lb Cl}} = \frac{64 \text{ lb KCl}}{\text{Acre 24 inch soil}} \text{ Or you could say 64 lb KCl/acre}$

#### Additional information and references

Clay, D.E., and K.D. Reitsma. 2009. Soil fertility. In Clay, D.E., K.D. Reitsma, and S.A. Clay (eds). *Best Management Practices for Corn Production in South Dakota*. EC929. South Dakota State University, SDSU Extension, Brookings, SD. Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/EC929.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC929.pdf)

Clay, D.E., S.A. Clay, C.G. Carlson, and S. Murrell. 2010. *Mathematics and Calculations for Agronomists and Soil Scientists*. International Plant Nutrition Institute. Available at <http://ppi-store.stores.yahoo.net/maandcaforag.html>

Clay, D.E., N. Kitchen, C.G. Carlson, J.L. Kleinjan, and W.A. Tjentland. 2002. Collecting representative soil samples for N and P fertilizer recommendations. Online. *Crop Management* doi:13.1094/CM-2002-12XX-01-MA.

Gelderman, R.H. 2009. Maximum fertilizer material to apply with seed. South Dakota State University, SDSU Extension, Brookings, SD. Available at <http://www.sdstate.edu/ps/service-labs-orgs/soil-test-lab/loader.cfm?csModule=securitygetfile&PageID=788496>

Gelderman, R.H., and L. Ulvestad. 2009. A summary of soil test results (July 2008 – June 2009). 2009 progressive report. Soil PR 09-5. South Dakota State University, SDSU Extension, Brookings, SD.

Gerwing, J., and R. Gelderman. 2005. Fertilizer recommendations guide. EC750. South Dakota State University, SDSU Extension, United States Department of Agriculture. Brookings, SD. Available at [pubstorage.sdstate.edu/AgBio\\_Publications/articles/EC750.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC750.pdf)

IPNI. 2013. A preliminary nutrient use geographic information systems (NuGIS) for the U.S. International Plant Nutrition Institute. Norcross, GA.

Korb, N., C. Jones, and J. Jacobsen. 2005. Nutrient Management Module No. 5. Potassium cycling, testing, and fertilizer recommendations. Montana State University Extension 4449-5. Available at <http://landresources.montana.edu/NM/Modules/mt44495.pdf>

#### Acknowledgements

Support for this chapter was provided by South Dakota State University, South Dakota Drought Tolerance Center, South Dakota Wheat Commission, and South Dakota Soybean Board.

---

Gelderman, R., and S. Lee. 2012. Phosphorus, potassium, sulfur, and chloride requirements. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.



## CHAPTER FOURTEEN

# Precision Wheat Management

Jiyul Chang ([Jiyul.Chang@sdstate.edu](mailto:Jiyul.Chang@sdstate.edu))

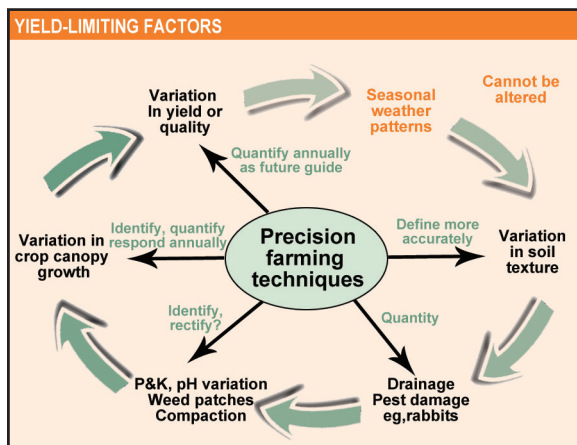
Kevin Dalsted ([Kevin.Dalsted@sdstate.edu](mailto:Kevin.Dalsted@sdstate.edu))

David Clay ([David.Clay@sdstate.edu](mailto:David.Clay@sdstate.edu))

C. Gregg Carlson ([Gregg.Carlson@sdstate.edu](mailto:Gregg.Carlson@sdstate.edu))

Three chapters in this publication discuss precision wheat management (Chapters 14, 15, and 16). Many people perceive precision agriculture as solely grid soil sampling and applying variable rate fertilizer applications. While these are two techniques used by producers, precision farming is a way of thinking rather than the adoption of new technologies. Precision farming uses local information to improve management (Fig. 14.1). Treatments can be applied using variable or non-variable rate equipment. The objectives of this chapter are to provide an overview and to

discuss guidelines for integrating precision farming into your operation.



**Figure 14.1. Reducing yield limiting factors with precision farming.**

(Source: <http://www.fwi.co.uk/Articles/23/08/2010/115957/Precision-farming-2-Crop-agronomy.htm>)

### *Precision farming overview*

Agriculture is being changed by improved low-cost informational technologies, molecular biology, and field equipment that provide the opportunity for implementing site-specific management. Through precision farming, all three technologies can be packaged and delivered to producers. Who would have thought 50 years ago that:

- A significant percentage of tractors, traversing our vast fields, would be traveling under the control of autosteer systems rather than driven by farmer-operators?
- A family operation could effectively farm 4000 acres?
- Our major defensive mechanisms in our battles with pests would come in our seed bags?
- Satellites would provide information needed to improve our management systems?

We are entering a new era in production agriculture, an era dominated by site-specific spatial management of farming inputs. This is an era where the agricultural foundations have undergone revolutionary changes. For centuries, agronomy was dominated by the biological sciences and the ability to work hard. Now we are witnessing an era where creativity and mathematics are becoming of equal importance. In precision agriculture, many of the current recommendation guidelines are being evaluated. Many of the concepts behind precision farming have been integrated into a number of books, such as:

*Site Specific Management Guidelines*

<http://ppi-store.stores.yahoo.net/sitmanguid.html>

*GIS Applications in Agriculture, 2007*

<http://www.crcpress.com/product/isbn/0849375266>

*Mathematics and Calculations for Agronomists and Soil Scientists*

<http://ppi-store.stores.yahoo.net/maandcaforag.html>

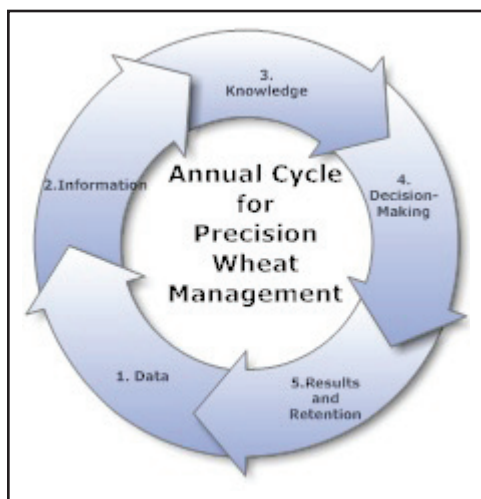
*GIS Applications in Agriculture: Nutrient Management for Improved Energy Efficiency*

<http://www.crcpress.com/product/isbn/0849375266>

It makes intuitive sense that site-specific recommendations are a function of the yield potential, climate, and soil variability. Areas with higher yield potentials often require higher inputs, while areas with lower yield potentials require less. In South Dakota, many fields contain significant spatial variability of yield, which is most often directly related to landscape position. Across these landscapes, water and salts are often the major factors that control yield.

In a given year, yields in the summit/shoulder areas are reduced by too little water, while yields in footslope/toeslope areas are reduced by too much water. In many fields, the availability of nutrients or occurrence of pests may further reduce these yields. To maximize yields and improve the efficient use of resources, inputs must be matched to the conditions existing at each landscape location. Precision farming provides the capability to convert locally derived information into improved decisions (Fig 14.2).





**Figure 14.2. Idealized annual process/cycle applied to precision wheat management.**  
(Source: Kevin Dalsted, SDSU)

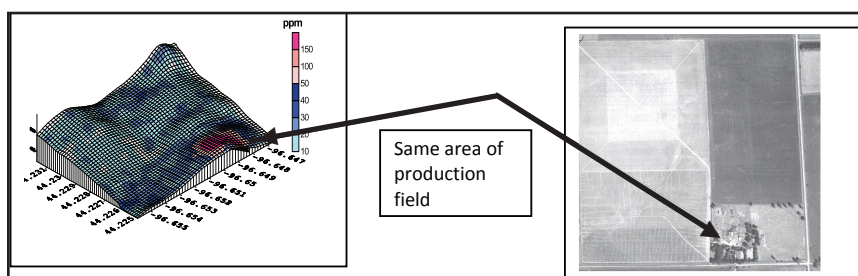
### ***Integrating precision farming into your operation***

All producers struggle to translate data into timely and informed decisions. The idealized management cycle is portrayed in Figure 14.2. Using soil fertility as the example, in Step 1 *data* (e.g., soil samples and associated lab data) is collected. Step 2 is deriving *information* from the lab data, such as comparing soil test values with fertilizer recommendations. Step 3 draws on the producers' *knowledge* (experience) to consider how and where to apply the fertilization by type, distribution and timing. Step 4 covers the final *management decision(s)* in a given year by translating the knowledge into the ground operations. Step 5 is the *post-harvest evaluation* when effectiveness of the practices is evaluated. What happened in a given year(s) can be used to tweak the first 4 steps, depending upon the situation (real and anticipated).

Making the best decision in a timely manner, given the circumstances of a particular year, is the key to profitability and sustainability. The application of precision agriculture to wheat management can aid in making these decisions. Many factors are beyond the control of the producer, such as weather, pests, crop prices, etc., but precision farming can aid in helping manage those factors that are within the control of the producer.

### ***Precision farming guideline highlights***

1. When using composite soil sampling, it is highly recommended to **not** include areas where old homesteads were located. Including these areas will reduce fertilizer recommendations, resulting in yield losses.



**Figure 14.3. The impact of prior management on current soil test values.** This homestead was removed from the landscape in the 1950s. The grid soil sampling was conducted in 1995. (Clay et al. 2006)



2. Yield monitor data can be used to partition fields into different categories. Two common categories are high yield – high stability and low yield – high stability. Software programs are available at South Dakota State University and The Upper Midwest Aerospace Consortium (UMAC)(Chapter 16).
3. Crop management zones can be developed on the basis of soils, yield monitor data, computer classification based on elevation or electrical conductivity, and/or crop spectral reflectance (Chapter 15). USDA soils data is readily accessible in a digital format (Chapter 18). Yield monitor and remote sensing data can be used to partition fields into zones (Fig. 14.4). Examples and case studies for determining zones are available in:

*GIS Applications in Agriculture*

<http://www.crcpress.com/product/isbn/0849375266>

*GIS Applications in Agriculture: Nutrient Management for Improved Energy Efficiency*

<http://www.crcpress.com/product/isbn/0849375266>

4. On-farm testing is a means of assessing current practices. In this approach, the experiments should be conducted over multiple years and replications should be included. Information about on-farm research is provided in Chapters 32 and 33. Questions about on-farm studies should be directed to Gregg Carlson ([gregg.carlson@sdstate.edu](mailto:gregg.carlson@sdstate.edu)).



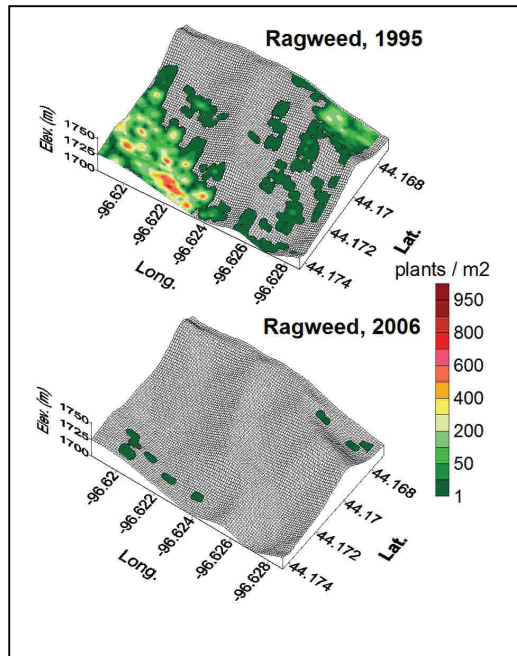
Figure 14.4. Several different approaches can be used to define management. (Modified by Clay et al.)

5. Profitability and nutrient removal maps can be developed. Nutrient removal rates for wheat are shown in Table 14.1. More information can be found in Chapter 12. Yield variations can result in differential removal rates. For example, areas of fields with yields of 60 and 40 bu/acre will remove 36 and 24 lbs  $P_2O_5$ /acre, respectively. If P was uniformly applied, then differential removal can result in relatively low concentrations in the high yielding area (Fig. 14.3). Nutrient removal maps can be developed with nutrient removal data below.

Table 14.1. Nutrient removal rates for wheat.

		Nutrient								
		N	$P_2O_5$	$K_2O$	B	Ca	Cu	Fe	S	Zn
Wheat	Lbs/	100								
Grain	bushels	150	60	34	0.1	3.3	0.083	0.75	10	35
Wheat	Lbs/ton	14	3.3	24					2.8	
Straw										

6. Fertilizer and pest management programs can be assessed by comparing maps or information from different years. Grid sampling for pests can be used to document pest management effectiveness (Fig. 14.5).



**Figure 14.5. Common ragweed (*Ambrosia artemisiifolia*) estimated densities in 65 ha field pre- (1995) and post (2006)-adoption of Roundup Ready® corn and soybean.** Weeds were counted at 2500 grid points in the eastern South Dakota field in the spring just prior to post-emergence weed control application. Conservation tillage was used in the field. (Modified from Chang et al. 2003)

### Precision farming tools

To implement adaptive management techniques, locally-based experiments must be conducted. Details about the design and analysis of these experiments are provided in Chapters 32 and 33. Yield monitors, scouting, remote sensing, and on-farm research are techniques to collect this data/information.

Data can be collected from these experiments using many different approaches.

Remote sensing data can be obtained from the South Dakota View <http://www.sdstate.edu/abe/sdview/index.cfm> or Upper Midwest Aerospace Consortium <http://dnngp.umac.org/newdnngp372/index.php>

The Upper Midwest Aerospace Consortium has written a program Digital Northern Great Plains that can be used to develop management zones. <http://dnngp.umac.org/newdnngp372/index.php>

A step-by-step guide for using this program is available in Clay and Shanahan (2011). [http://www.crcpress.com/product/isbn/9781420092707;jsessionid=OkXJUfa2dnIDJp2H5EsiQ\\*\\*](http://www.crcpress.com/product/isbn/9781420092707;jsessionid=OkXJUfa2dnIDJp2H5EsiQ**)

Soils information can be obtained from the USDA-NRCS soils database. See Chapter 18. <http://soils.usda.gov/survey/geography/ssurgo/>

Multiple years of yield monitor data/information can be used to identify management zones and assess the effectiveness of various treatments. Step-by-step protocols for deriving knowledge from soil information/data and field scouting are available in the *GIS Applications in Agronomy* book series. <http://www.crcpress.com/product/isbn/0849375266>

One of the most widely used approaches for collecting on-site data/information is to measure the apparent electrical conductivity (ECa). Systems for measuring ECa are manufactured and marketed by Veris Technologies (Salina, Kansas) <http://www.veristech.com/products/soilec.aspx> and Geonometrics Limited (Mississauga, Ontario).

Data from these systems can be linked with latitude and longitude information collected with differentially corrected global positioning systems (DGPS) so as to develop elevation contour maps. These systems are used to:

- Identify management zones.
- Identify yield-limiting factors.
- Conduct a rapid identification of farm field variability.
- Provide guidance for soil sampling.
- Provide information about soil discontinuities.

### ***Global positioning and geographic information systems***

Many current precision farming applications rely on differentially corrected global positioning systems (DGPS). With DGPS the latitude and longitude values at specific points are identified. DGPS, or similar systems, is used by self-guided tractors (Autosteer), parallel swathing, and grid soil sampling.

Another important precision agriculture component is geographic information systems (GIS). GIS allow the user to display a variety of digital maps and their associated attributes. The Web Soil Survey web site is a great example of a data source that shows the potential of GIS applications (Chapter 18). Furthermore, using GIS functions can bring together various levels of data, such as potential yields by soil map units compared to the actual yield map coupled with an annual rainfall distribution map. Comparing multiple years of field data can also be informative.

From a user's perspective, one way of looking at GIS is to consider the "staying power" of the digital maps and its associated data attributes. For example, a digital topographic map with its elevation information can be thought to be relatively stable (earthquakes, mudslides and human activities, notwithstanding); depth to aquifer, vegetation climate zone, and soil survey maps are a few other examples.

Intermediate "stability" might be illustrated by annual cropping land cover maps, periodic census counts (human or wildlife), and annual fertilizer usage. Short-term examples could include daily relative humidity numbers, rain accumulations, wind speed, etc. The reason for discussing these three levels is to illustrate the need to consider collection frequency. As some data expire quickly, they need to be refreshed more often than the so-called stable data.

[http://www.ebookpdf.net/ebook-pdf\\_gis-applications-in-agriculture\\_1093.html](http://www.ebookpdf.net/ebook-pdf_gis-applications-in-agriculture_1093.html)

In summary, precision farming is an approach where locally derived information and knowledge is integrated into the decision process. There are many tools that can be used to help implement these decisions. Currently research is being conducted to better define and refine the site-specific management recommendations as well as develop new tools that simplify the processing of such information. As the mountain of data accumulates for producers, tools associated with precision agriculture will provide an effective means of scaling that mountain, while preserving the integrity and value of the data/information/knowledge and providing the all-important time efficiencies that are needed.

#### Additional information and references

Berry, J.K. 1999. *The Precision Farming Primer*. Basis Inc. Available at <http://www.innovativegis.com/basis/pfprimer/>

Chang, J., D.E. Clay, C.G. Carlson, S.A. Clay, D.D. Malo, R. Berg, and W. Wiebold. 2003. The influence of different approaches for defining nutrient management zone boundaries on N and P recommendations. *Agron. J.* 95:1550-1559.

Clay, D.E., and J.F. Shanahan (eds). 2011. *GIS Applications in Agriculture: Nutrient Management for Improved Energy Efficiency*. Volume 2. Available at <http://www.crcpress.com/product/isbn/0849375266>

Clay, D.E., N.R. Kitchen, C.G. Carlson, and J.L. Kleinjan. 2006. The first step in precision agriculture: sampling old farmsteads separately from the rest of the field. SSMG 43. In Clay et al. (eds). *Site Specific Management Guidelines*. Potash and Phosphate Institute. Norcross, GA.

Clay, D.E., S.A. Clay, and K. Reistma (eds). 2009. *Best Management Practices for Corn Production in South Dakota*. EC929. South Dakota State University, SDSU Extension, Brookings, SD. Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/EC929.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC929.pdf)

Clay, D.E., S.A. Clay, C.G. Carlson, and T.S. Murrell. 2010. *Mathematics and Calculations for Agronomists and Soil Scientists*. International Plant Nutrition Institute. Available at <http://ppi-store.stores.yahoo.net/maandcaforag.html>

Logsdon, S., D.E. Clay, D. Moore, and T. Tsegaye (eds). 2008. *Soil Science: A Step-by-Step Field Analysis*. Soil Science Society of America. Madison, WI. Available at <https://portal.sciencesocieties.org/Resources/Files/downloads/pdf/B60915.pdf>

Pierce F.J. and D. Clay (eds). *GIS Applications in Agriculture*. 2007. CRC Press, Taylor and Francis, New York, NY. Available at <http://www.crcpress.com/product/isbn/0849375266>

Veris Technologies: [www.veristech.com](http://www.veristech.com)

#### Acknowledgements

Support for this chapter was provided in part by South Dakota Soybean Research and Promotion Council, South Dakota Corn Utilization Council, South Dakota Wheat Commission, NASA through the Upper Midwest Aerospace Consortium and the SD Space Grant Consortium, USDA-NCSARE, the South Dakota Agricultural Experiment Station, USDA-CSREES, and SD 2010 Initiative.

---

Chang, J., K. Dalsted, D.E. Clay, and G. Carlson. 2012. Precision wheat management. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.





## CHAPTER FIFTEEN

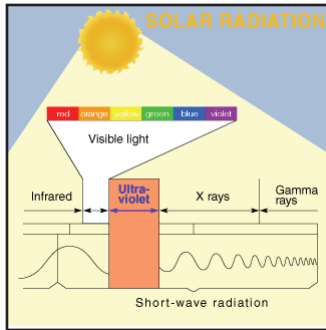
# Using Canopy Reflectance Sensors for Managing N in Wheat

Cheryl Reese ([Cheryl.Reese@sdsstate.edu](mailto:Cheryl.Reese@sdsstate.edu))

Chapters 1 and 8 both discuss the importance of in-season N application. One approach to implement in-season N is to utilize crop reflectance for assessing yield-limiting factors. This chapter will provide users with the scientific background on how to use and evaluate the potentials of canopy reflectance sensors.

### **Introduction**

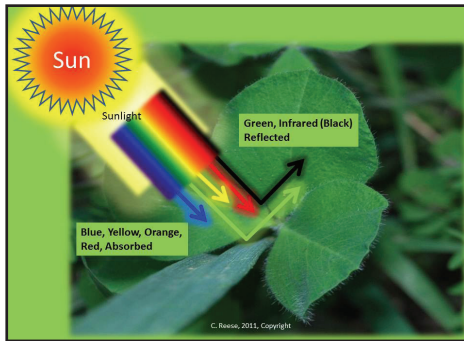
Most commercially available remote sensing sensors collect information from the visible and near infrared portion of the electromagnetic spectrum (Fig 15.1). This information can be used to identify healthy and stressed plants. If the yield-limiting factor affects the plant's reflectance, then remote sensing data may be used to help develop prescriptions. Wheat yields in many South Dakota fields are limited by both N and water stress, which in turn impact the accuracy of crop reflectance N-based recommendations. Given the complexity of our soils, we recommend that reflectance-based N recommendations be checked for accuracy. Misdiagnosing a problem (for instance, N for water) can reduce yields and profitability. The use of well-fertilized check plots can reduce errors.



**Figure 15.1. Electromagnetic spectrum.**  
<http://serc.carleton.edu/usingdata/nasaimages/index4.html>

### *Using crop reflectance to assess plant stress*

When sunlight (energy) strikes a plant leaf, the energy can be absorbed (photosynthesis), reflected or transmitted (i.e., pass through the leaf) (Fig. 15.2). The energy source used in photosynthesis is in the visible light range. Leaves reflect more green light than the other visible bands (blue and red light), which is why plants look green. The energy in the near infrared (NIR) area is mostly reflected by healthy growing plants (Fig 15.2).



**Figure 15.2. Sunlight interactions at the surface of a leaf.** (Source: C. Reese, 2011)

Enhancing information from the electromagnetic spectrum through transformations can improve its usefulness. Two useful transformation indices are the Normalized Difference Vegetation Index:

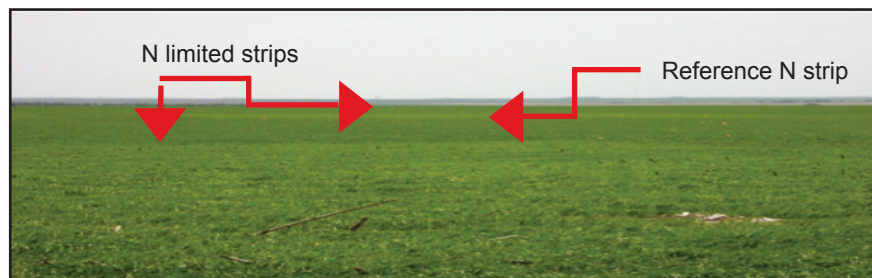
$$NDVI = (NIR - Red) / (NIR + Red)$$

and the Green Normalized Difference Vegetative Index:

$$GNDVI = (NIR - Green) / (NIR + Green)$$

<http://landsat.gsfc.nasa.gov/>

Based on differences in the reflectance, prescriptions can be produced (Fig. 15.3. Clay and Shanahan 2011).



**Figure 15.3. An N limited and well-fertilized reference N strip in a South Dakota hard red spring wheat field.** (Source: C. Reese, 2011)



### Commercially available sensors

Commercially available sensors can be mounted on equipment or hand held. These sensors can operate in a range of light conditions by emitting energy (active systems generate their own illumination) at specified wavelengths. The energy reflected at these wavelengths is measured and recorded (Fig. 15.4). Various LED sensors are available to record data across a wide range of the electromagnetic spectrum. Based on the reflectance signature relative to check strips, a prescription is developed.

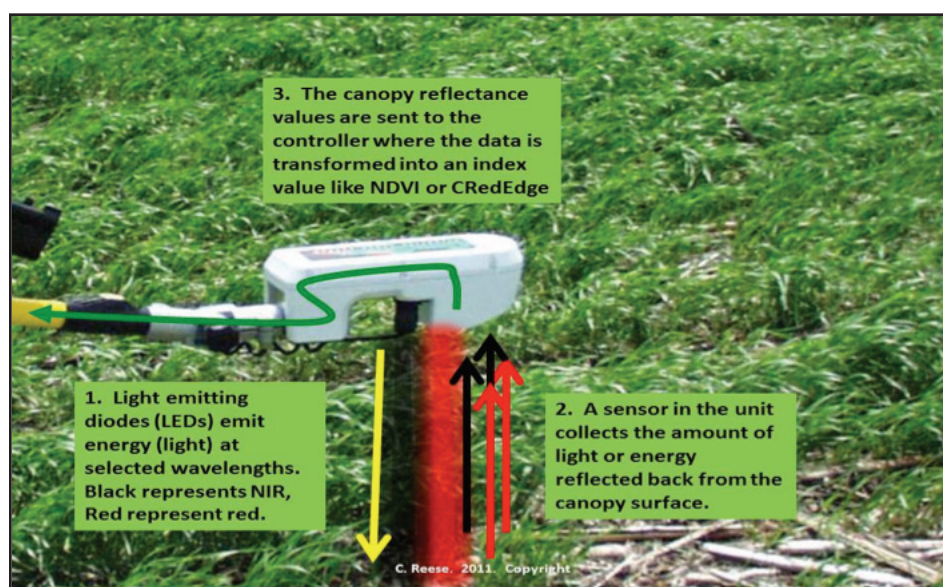


Figure 15.4. Canopy reflectance sensor operation. (Source: C. Reese, 2011)

### Greenseeker®

The Greenseeker sensor system is sold through Trimble (740 South State Street; Ukiah, CA 95482; 1-888-728-2436 or [gs-ws\\_info@trimble.com](mailto:gs-ws_info@trimble.com)). The sensors can be mounted on a sprayer or fertilizer applicator (Fig. 15.5). The hand-held device uses either Trimble Recon® or Nomad® data loggers to record canopy reflectance. The Trimble Recon can connect to Trimble's GPS Pathfinder® receivers while the Nomad has a built-in GPS. The sprayer-mounted models RT200-N and RT200-FmX are compatible with rate controllers marketed by JD Greenstar, Raven, Rawson, Field IQ, and EZ Boom.

Manuals for the Greenseeker sensor systems are available at <http://www.ntechindustries.com/manuals.php>.

Greenseeker sensors are configured to calculate a variety of indices including:

- 1) NDVI
- 2) SA-NDVI  $[(R_{774} - R_{656}) / (R_{774} + R_{656})] (1 + L)$
- 3) RVI  $(R_{774} / R_{656})$
- 4) IRVI  $(R_{656} / R_{774})$

$R_{774}$  and  $R_{656}$  are the reflectance values at those wavelengths. For additional information about Greenseekers for South Dakota applications, contact GreenSeeker and WeedSeeker Sales Office (740 South State Street; Ukiah, CA 95482; 1-888-728-2436 or [gs-ws\\_info@trimble.com](mailto:gs-ws_info@trimble.com)).



**Figure 15.5. Sprayer mounted Greenseeker sensors (RT100, RT200-N, RT200-FmX).**  
(Source: Jim Logg, Trimble.com, 2011)

### ***Crop Circle®***

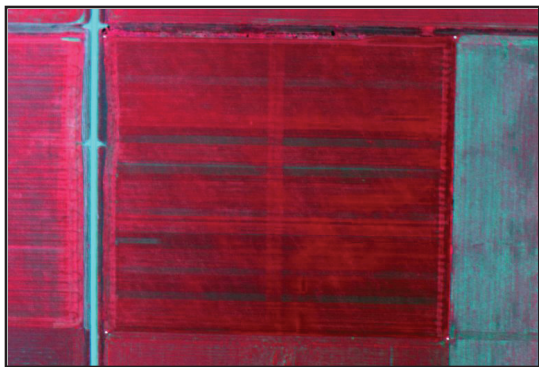
Holland Scientific Inc. (6001 S. 58th Street, Suite D; Lincoln, NE 68516; 1-402-488-1226) manufactures Crop Circle sensors and has also partnered with Ag Leader through their OptRX ACS430® sensor. Holland Scientific Inc. has sensors available that can be placed on sprayers, aircraft, or tractor cabs. Data loggers for the sensors are the GeoScout GLS-400® or GLS-420®. Collecting geo-referenced data with the GeoScout data loggers is easy because the data logger has a separate port for the sensor and a global positioning system (GPS) unit. In addition, the data is stored on a SD flash card, much like those used in digital cameras, so transferring data between the sensor and a desktop computer is seamless.

Rate controllers are compatible with a range of controllers marketed by Bogballe, Kvemeland, Agro LH 5000, Raven Industries, Rawson Accurate, and Holland Scientific. Based on measured reflectance values, a wide range of indices values can be calculated.

### ***Calibrating sensors***

The Greenseeker and Crop Circle sensors can be calibrated using a variety of approaches including placing N-rich strips in the field and two techniques that do not require reference strips. An N-rich strip is a reference strip placed in the field around planting time. The N-rate applied in the N-rich strip should be at least 100% the total N requirement throughout the growing season (Fig. 15.6). Ideally, the length of the N-rich strip should be the length of the field. If the length of the field is not possible, the minimum length should be 400 ft. The strip should be placed in an area that “best” represents field conditions (Clay and Shanahan 2011).

The last two approaches do not rely on N strips. The first non-N strip approach is the Virtual Reference Strip (VRS). With this method, the producer ‘drives’ several transects to calibrate the sensor. The second method is the “Drive and Apply” approach. Using this technique, the producer just starts applying N and the sensors adaptively calibrate to the crop’s physiological condition. For South Dakota fields, we do not recommend the use of non-reference strip calibration techniques.



**Figure 15.6. N-rich strips used to calibrate remote sensing-based N recommendations.**

(Source: C. Reese, 2011)

#### Additional information and references

Clay D.E., and J.F. Shanahan. 2011. *GIS Applications in Agriculture: Nutrient Management for Improved Energy Efficiency*. Volume 2. Available at <http://www.crcpress.com/product/isbn/0849375266>

Clay, D.E. et al. (eds.). *Site Specific Management Guidelines*. 19915. Potash and Phosphate Institute. Available at <http://www.ppi-far.org/ssmg>

<http://www.npk.okstate.edu/referencestrips>

[http://www.ntechindustries.com/lit/technotes/How\\_to\\_use\\_Crop\\_Algorithms\\_080606.pdf](http://www.ntechindustries.com/lit/technotes/How_to_use_Crop_Algorithms_080606.pdf)

#### Acknowledgments

Support was provided by USDA, South Dakota Experiment Station, SD Drought Tolerance Center and the South Dakota Wheat Commission.

---

Reese, C. 2012. Using canopy reflectance sensors for managing N in wheat. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.





## CHAPTER SIXTEEN

# Space-based Precision Farming Wheat Management Tools

Soizik Laguette ([Laguette@aero.und.edu](mailto:Laguette@aero.und.edu))

The purpose of this chapter is to discuss spaced-based precision farming tools that have been developed for producers in the Dakotas, Montana, Wyoming, eastern Minnesota, and Idaho. Numerous sources of no-cost remote sensing data and decision tools are available at <http://www.umac.org/>.

### **Introduction**

Precision agriculture technologies enable producers to take into account data from multiple sources and to develop efficient management practices based on the spatial and temporal variability of crop production. Geospatial technologies include remote sensing data, other spatial data, and software tools that enable users to make effective management decisions based on spectral, temporal, and locational relationships. The tools associated with geospatial technologies can help address agricultural needs for rapid analysis (interpretation and decision-making).

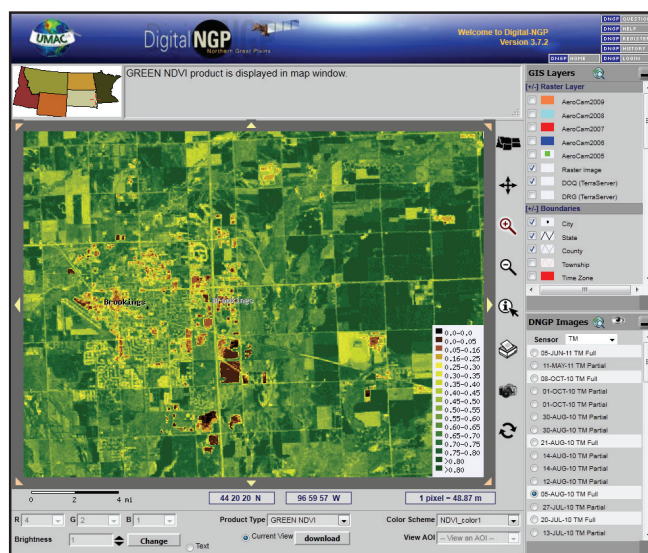
Remote-sensed information can be used alone, or synthesized with information from other sources, allowing for consideration of more variables in the decision-making process. The Upper Midwest Aerospace Consortium (UMAC), which is funded by NASA, has been developing decision tools for producers and ranchers in South Dakota, North Dakota, eastern Minnesota, Montana, Wyoming, and Idaho.

UMAC has developed:

- *Digital Northern Great Plains (DNGP)*: a geospatial data archive, one of the largest collections of satellite imagery and geographic information systems (GIS) layers freely available in the UMAC region.
- *ZoneMAP*: a web-based decision-support tool to develop variable zone application maps.



- *AEROCam* and *ISSAC*: two sensors designed for land and agricultural management, operating on an aircraft and on-board the International Space Station (ISS), respectively.



**Figure 16.1. DNGP screen-shot: Displaying a Landsat TM image over Brookings, SD, acquired on June 5, 2010.** Product selected is GreenNDVI. Panels list available GIS layers (upper right) and all the images covering the area (lower right). (Source: DNGP)

### *Digital Northern Great Plain (DNGP)*

<http://dngp.umac.org/newdngp372/index.php>

DNGP is a web-based geospatial data archive providing free access to downloadable satellite and airborne imagery and image-derived products such as NDVI (Table 16.1 and Fig. 16.1). DNGP is structured and designed based on two open source packages, GDAL (Geospatial Data Abstraction Library), which is a translator library for raster geospatial data formats, and MapServer, which is a platform for publishing spatial data and interactive mapping applications to the web (Zhang et al. 2010a).

DNGP delivers low- to medium-high and high-resolution multispectral data sets. The archive collection goes back 30 years. Current accessible images came from satellites and sensors described in Table 16.1. All accessible images are terrain corrected data, which includes atmospheric, radiometric, and geometric correction and orthorectification, and therefore, the images are compatible with other geographic maps or geo-referenced data sets such as yield, soil, soil electrical conductivity maps, etc.

Currently AEROCam data (aircraft-based) are typically only corrected radiometrically. However, geometric correction, including orthorectification, can be done on a request basis. ISSAC's first image was acquired in June 2011. Higher quality level data delivered should be terrain corrected, i.e., data delivered should be radiometrically and atmospherically corrected, as well as geo-referenced.

DNGP users have the option to download data in a raster format or in a text file format, compatible with precision farming software tools. These text files contain the latitude and longitude of the center point of each pixel and the data value for this pixel. DNGP allows users to define and save their own image sub-sets, also named Area of Interests (AOIs), to simplify recurring access to data over the same field or location, and/or facilitate the download operation even with slow Internet connection.

<b>Table 16.1. DNGP — Satellite and sensors imagery available to users.</b>			
<b>Satellite/sensors</b>	<b>Spatial resolution (Pixel size)</b>	<b>Bands and products downloadable</b>	<b>Temporal resolution</b>
<i>Low to Medium-high resolution</i>			
Landsat MSS, TM, ETM+	TM-ETM+: 30m MSS: 60m	Band 1 to 7 - True and false color NDVI & Green NDVI	16 days
ASTER	15m VNIR 30m SWIR	Green, Red, NIR NDVI & Green NDVI	1 week
MODIS	250m	Red & NIR Natural color composite NDVI & Green NDVI	
ISSAC	20-18m	Green, Red & NIR NDVI & Green NDVI	On-request
<i>High resolution</i>			
AEROCam Airborne sensor	2m to 0.5m	Blue, Green, Red or Green, Red, NIR	On-request
Shuttle Radar Topo. Mission	30m	Elevation (surface relief) data	

### ***Zone Mapping Application for precision farming (ZoneMAP)***

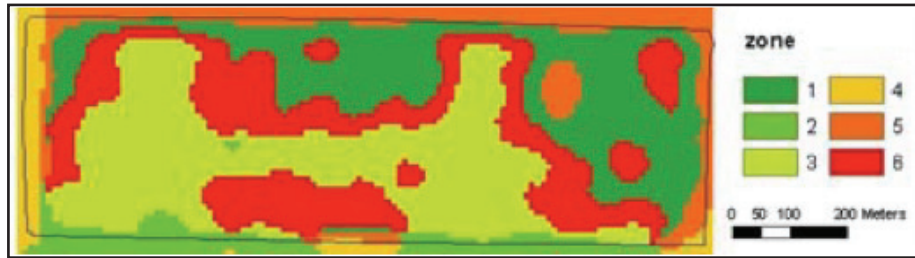
<http://zonemap.umac.org/>

ZoneMAP is a decision support tool that captures variations in nutrient content, yields, or plant conditions using information provided by remote sensing technology and/or routine field surveys. ZoneMAP can use yield monitor or remote sensing data. It helps users design variable rate application maps. The algorithm used to create ZoneMAP clusters is the Fuzzy C-means. ZoneMap is internally linked to DNGP, the UMAC geospatial data archive.

ZoneMAP computes the optimal number of management zones and their delineation over an area based on satellite imagery, accessed directly from DNGP or provided by users, and field data provided by users (Fig. 16.2). Satellite images are cropped automatically to the area of interest (AOI) defined by users, and are re-projected and re-sampled to a common projection plan with a pixel size defined by users. Users can also input other types of data such as yield, soil or soil electrical conductivity, to be used during the cluster process. Those data must be in a classical grid text format (latitude, longitude, and parameters values) or in a raster format.

All created maps are saved in a secure online database, and every map is automatically associated with its metadata file describing the procedure and data set used for the classification. Users can input an application rate to generate a variable rate application map. Final output maps can be downloaded in raster, text, or shape file format with a wide number of possible map projections (Fig. 16.2). ZoneMAP can be accessed at <http://zonemap.umac.org/>.



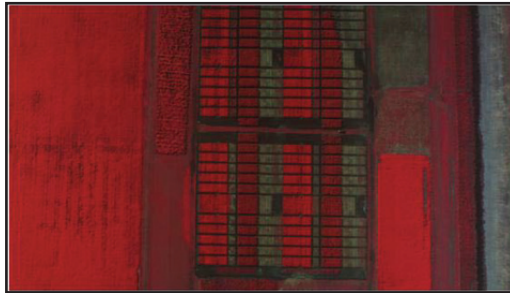


**Figure 16.2.** A management zone map produced using space-based information collected in the Fall of 2003. (Zhang et al. 2010b)

### *AEROCam*

The Airborne Environmental Research Observational Camera (AEROCam) is an airborne multispectral sensor offering near real-time high resolution imagery to a variety of end-users throughout the UMAC region (Fig. 16.3). AEROCAM sensor is a Redlake MS4100 multispectral sensor, blue-green-red-near infrared, providing true color (blue, green, red) or false color (green, red, near infrared) images. Typically AEROCam images are only corrected radiometrically. Geo-rectification is not automatic but can be performed at user's request. If performed, delivery of a geo-rectified product takes several weeks or longer. AEROCam spatial resolution is typically 1 meter, but can range from 2 to 0.5 meters at user's request. AEROCam data are acquired on demand and are accessible through DNGP.

South Dakota users can request AEROCam imagery by filling out a request form. The AEROCam request form can be accessed at <http://www.umac.org/sensors/aerocam/index.html>.



**Figure 16.3.** Aerocam false color imagery shows agronomy trial plots at North Dakota State University in Fargo, ND. The strength of red colors relates to plant vigor and health.

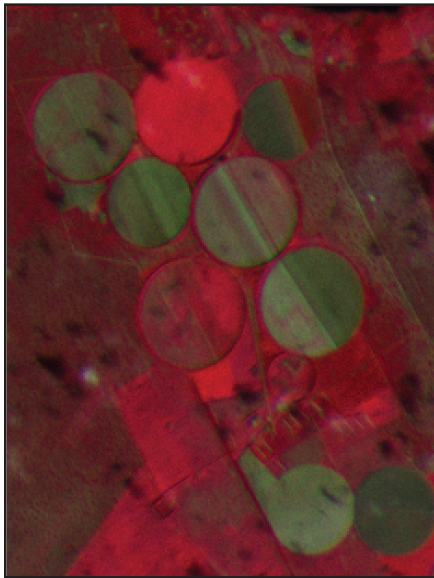
### *ISSAC*

The International Space Station Agricultural Camera (ISSAC) is a three-band multispectral sensor, green-red-near infrared, on board the International Space Station (Fig. 16.4). ISSAC's first image was taken on June 10, 2011. However, images still need to be tested and calibrated before they can be distributed to users. Following onboard testing and calibration, farmers, ranchers, land-use managers and researchers in the UMAC region will begin benefitting from these space images.

The sensor is expected to have a spatial resolution of 18 to 20 meters. ISSAC near real-time delivered products are planned to be the following:

- L0: raw uncorrected image (current stage)
- L1R: radiometric correction
- L1G: L1R plus geo-referenced data
- L2A: L1G plus atmospheric correction

Data will be acquired on request, and images will be accessible through DNGP, as well as the other ISSAC image-derived products such as NDVI and GreenNDVI.



**Figure 16.4. ISSAC image (06/10/2011, raw uncorrected data) taken over agricultural fields near Natal, Grande Rio do Norte, Brazil. False color composite with reds depicting growing plants.**

ISSAC website can be accessed at <http://www.umac.org/sensors/issac/index.html>.

ISSAC's purpose-built web application, Imagery Request and Information System (IRIS) can be accessed at <http://www.umac.org/iris/login.html>.

## **Glossary**

### **Geospatial technologies**

Any of a wide range of information technologies dealing with land/water, which have a locational reference (i.e., geographic or spatial coordinate systems). This includes GPS, GIS, remote sensing, land surveying, among others.

### **Electromagnetic spectrum**

Energy that is characterized by wavelength and/or frequency, including gamma radiation, ultraviolet energy, visible light (reflected), near infrared light (reflected), thermal energy (emitted) and microwave energy.

### **Multispectral data**

Data recorded by sensors that are sensitive to defined regions of the electromagnetic spectrum; typically land managers use data from the visible and near infrared areas.

### **Remote sensing**

The art and science of collecting/recording data from a distance utilizing the electromagnetic spectrum. The distances can be very close or very far satellite sensors and telescopes.

### **Pixel**

Short for picture element and represents the smallest division of a picture or image.

### **Raster format**

A data format that relates to a row-column array of data over a geographic area. For example, a 20 m pixel represents an area on the ground that is 20 m on one side, typically with one reflectance value. One single scene of remote sensing data will be made up numerous pixels by spectral band, each of which is separate. Composite images are made by overlaying multiple bands (co-registered) to generate various color products (e.g., true color or color infrared).

### **Rectification**

A process of eliminating various distortions in imagery/photography, and it focuses generally on eliminating scale variations to the extent possible.

### **Radiometric correction**

A preprocessing procedure conducted in order to remove noise and/or other distorting contributions (atmospheric, sun angles, etc.) to digital numbers (DN), which is the numerical spectral value for a given pixel.

### **NDVI**

Normalize Difference Vegetation Index, a calculation on a pixel-by-pixel basis that generally enhances the visualization of growing vegetation. It is generated by an algorithm that uses this visible and near-infrared data: *near infrared value – visible (usually red) value divided by near infrared + visible values*. It takes advantage of the fact that growing vegetation is very highly reflective in the near infrared region, but is not as reflective when under stress or not growing.

#### Additional information and references

Zhang X., S. Seelan, and G. Seielstad, 2010a. *Digital Northern Great Plains: A web-based system delivering near real time remote sensing data for precision agriculture*. *Remote Sensing*, 2(3):861-873.

Zhang, X., L. Shi, X. Jia, C. Helgason, and G. Seielstad, 2010b. *Zone mapping application for precision-farming: a decision support tool for variable rate application*. *Precision Agriculture*, 11(2):103-114.

Zhang, Xiaodong. 2011. *Digital Northern Great Plains and zone mapping application for precision agriculture*. In Clay, D.E., and J.F. Shanahan (eds). *GIS Applications in Agriculture: Nutrient Management for Energy Efficiency*. Volume 2. CRC Press and NC SARE, New York, NY.  
Available at <http://www.crcpress.com/product/isbn/9781420092707>

#### Acknowledgements

UMAC's work has been partially funded by a series of grants from NASA. The author is reporting the efforts of a much larger team who have been working on these projects for several years.

---

Laguet, S. 2012. Space-based precision farming wheat management tools. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.





## CHAPTER SEVENTEEN

# Arbuscular Mycorrhizal Associations and Their Significance for Wheat Production

Heike Bücking ([Heike.Bucking@sdstate.edu](mailto:Heike.Bucking@sdstate.edu))

Parvathi Jampani ([Parvathi.Jampani@sdstate.edu](mailto:Parvathi.Jampani@sdstate.edu))

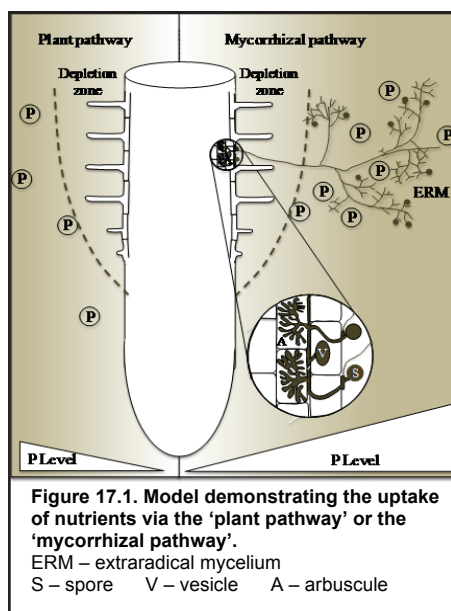
Jose Gonzalez ([Jose.Gonzalez@sdstate.edu](mailto:Jose.Gonzalez@sdstate.edu))

Arbuscular mycorrhizal (AM) fungi have the capacity to form symbiotic relationships with important crop species, such as wheat, corn, soybean and rice. The colonization with AM fungi provides numerous benefits for the host plant including an increased uptake of nutrients and an enhanced resistance against plant pathogens and other stresses such as drought, salinity, and heavy metals. In return, the plant transfers up to 20% of its photosynthetically produced carbohydrates to the fungus. The AM fungus is an obligate symbiont that relies on the host-derived carbon to reproduce and to complete its life cycle.

In South Dakota, research on using soil microorganisms to improve nutrient and water-use efficiency is just starting. The key role of these ubiquitous soil fungi for plant productivity and health, however, has prompted agronomic interest in these interactions with regard to a potential use as ‘biofertilizers and bioprotectors’ in sustainable agriculture. This chapter summarizes our current knowledge on the significance of AM fungi for wheat productivity and discusses agricultural practices that stimulate the AM colonization of the plant.

### ***Nutrient uptake of arbuscular mycorrhizal plants***

The most important benefit of the AM symbiosis for the plant is the improvement in the supply with nutrients, such as P, N, K and S, but also with trace elements, such as Cu and Zn. In general, an AM colonization is beneficial for the host plant as long as the net costs of the symbiosis for the host plant (carbon costs) are lower than the net benefits (increase in nutrient uptake) (Johnson et al. 1997).



Plants can take up nutrients via the 'plant pathway' or via the 'mycorrhizal pathway' (Fig. 17.1). The 'plant pathway' involves the uptake via the nutrient-absorbing surface area of the root, particularly the root hairs. The low mobility of many nutrients in the soil (e.g., P), however, leads to the development of depletion zones around the roots that often limit further nutrient uptake.

The 'mycorrhizal pathway,' on the other hand, involves the uptake of nutrients from the soil via the extraradical mycelium (ERM) and the transfer to highly branched, tree-like structures within the plant root cells, the arbuscules, which release the nutrients to the host plant. The ERM of the fungus extends the nutrient-absorbing surface of the root substantially beyond the depletion zone, thus providing access to nutrients in a larger soil volume.

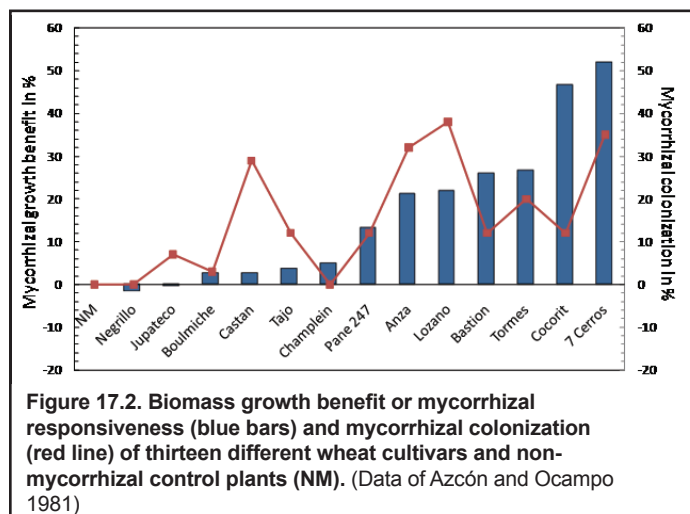
In addition, AM fungi are also able to take up organic nutrient resources that are not available for the host. According to estimates, the 'mycorrhizal pathway' is responsible for 50 to 80% of the plant's P (Li et al. 2006) and for 75% of the plant's N uptake (Tanaka and Yano 2005).

Despite relatively high total P soil contents, crop productivity in many soils is limited by P, and many crops show a relatively low responsiveness to P fertilizer (Holloway et al. 2001). The P fertilizer use efficiency (PUE) of wheat can be as low as 8 to 16%, and decreases with increasing P soil concentrations. The grain purchasing power of P fertilizer is low (Karamanos 2007; Mosali et al. 2006). This is due to the fact that plants are not able to store nutrients very efficiently and the nutrient uptake capacity is regulated by the demand. AM fungi, on the other hand, are able to store P as polyphosphate, which allows the fungus to provide the host plant continuously with P even if soil P levels decrease. This characteristic of AM fungi could be helpful in increasing the PUE of agricultural systems (Singh and Singh 2008).

### ***Mycorrhizal fungi contribution to nutrient uptake and productivity in wheat***

Published data about the mycorrhizal colonization rate in wheat roots range from 10 to 80% colonized root length (Li et al. 2005; Sharif and Nasrullah 2009). Despite relatively high colonization rates, the mycorrhizal dependency of wheat has been considered as relatively low with potential yield losses of 10 to 30% without an AM colonization (Queensland Government 2011). It has been suggested that wheat may not benefit from the AM symbiosis due to its relatively large and highly branched root system and dense root hairs (Graham and Abbott 2000; Zhu et al. 2001).

However, our own studies and the results of other authors suggest that wheat cultivars differ in their response to AM fungi and that mycorrhizal benefit depends on the nutrient supply conditions. We examined the mycorrhizal dependency of different wheat cultivars under various nutrient supply conditions and found that under low nutrient level, some wheat cultivars showed yield increases of 60% after colonization with AM fungi. The yield gains of mycorrhizal plants was higher in some varieties than in others.



Azcón and Ocampo (1981), who tested the mycorrhizal responsiveness of thirteen different wheat cultivars, found biomass gains of more than 40% in some cultivars, and low or slightly negative growth responses in other cultivars (Fig. 17.2, blue bars). However, it should be noted that, in general, the plants with negative or low positive growth responses showed relatively low mycorrhizal colonization rates (Fig. 17.2, red line).

Hetrick et al. (1992) concluded

that genotypic differences depend on the root architecture and that higher mycorrhizal benefits can typically be found in genotypes with a lower root fibrousness.

Zhu et al. (2001) reported that wheat varieties developed before 1900 had a higher responsiveness than modern varieties. However, modern varieties from the U.S. or Great Britain also showed biomass increases of 29 to 100% following an inoculation with AM fungi (Hetrick et al. 1992). Even wheat varieties that were considered not susceptible to AM fungi showed high colonization rates under field conditions (Li et al. 2005).

In our experiments, the mycorrhizal dependency was, in general, lower when more nutrients were supplied. Under high nutrient supply conditions, no effects or growth reductions were observed as a result of the AM colonization. However, a low mycorrhizal responsiveness does not mean that the AM fungus does not contribute to wheat nutrient uptake (see above, Li et al. 2006; Schweiger and Jakobsen 1999). It has been suggested that the uptake via the plant pathway is not affected by the AM symbiosis and that the 'plant pathway' and 'mycorrhizal pathway' act additively. This has led to the assumption that the uptake via the mycorrhizal pathway can be neglected, when P fertilizers are added and AM plants don't show a positive growth response. This view, however, is now being questioned (Smith et al. 2009a; Smith et al. 2009b).

Mycorrhizal wheat has been shown to take up more P from the soil than non-mycorrhizal plants, regardless of growth responses (Ravnkov and Jakobsen 1995). Li et al. (2006) estimated that in non-responsive wheat plants, 50 to 80% of the P was taken up via the mycorrhizal pathway. Schweiger and Jakobsen (1999), who studied the P uptake and transport via the mycorrhizal ERM to winter wheat, reported that, even at typical field soil fertility levels of 28  $\mu\text{g NaHCO}_3$  extractable P  $\text{g}^{-1}$  soil, the AM fungus contributes significantly to the P uptake of the plant. This indicates that:

1. In mycorrhizal plants, the P uptake via the plant pathway is reduced.
2. Mycorrhizal wheat changes its nutrient uptake strategy and shifts the responsibility for nutrient uptake from the plant to the mycorrhizal pathway.
3. Even under conditions in which P fertilization limits the mycorrhizal responsiveness, the AM fungus contributes to P uptake.



These findings should have important implications and demonstrate that the mycorrhizal responsiveness should be considered as an important trait in crop breeding programs that seek to increase the nutrient efficiency of wheat.

### ***AM colonization impacts on stress resistance in wheat***

In addition to the positive effects on nutrient uptake, AM fungi can also increase the resistance of plants to a variety of other stresses. For example, drought stress is often considered to be the most significant factor restricting crop productivity world-wide, and therefore the development of wheat genotypes and management techniques that improve drought stress tolerance represents an urgent research priority (Hagyó et al. 2007).

Many authors have shown that the AM symbiosis can improve the drought resistance of plants, and mycorrhizal wheat plants had an almost 40% higher biomass and grain yield under drought stress compared to non-mycorrhizal control plants (Al-Karaki et al. 2004).

The cadmium levels in grains of Durum wheat harvested in some areas of the Northern Great Plains already exceed the maximum permissible concentration recommended by the World Health Organization (Wolnick et al. 1983). It can be expected that these levels will further increase, since the declining purity of phosphate rock reserves and P fertilizers will increase the heavy metal input in agricultural soils. AM fungi alleviate the stress response of plants to heavy metals (Aloui et al. 2011), and have also been shown to increase the tolerance of wheat to high salt concentrations (Daei et al. 2009).

Spring and winter wheat productivity in South Dakota and the Northern Great Plains is challenged by many fungal pathogens, such as *Fusarium* head blight, rusts, the leaf spot complex and the root rot complex. *Fusarium* head blight, for example, was responsible for \$34 million in crop losses in 2005. AM fungi have been shown to increase plant resistance particularly against root pathogens.

Particularly important is the bioprotection conferred to plants against *Aphanomyces*, *Cylindrocladium*, *Fusarium*, *Macrophomina*, *Phytophthora*, *Pythium*, *Rhizoctonia*, *Sclerotinium*, *Verticillium*, *Gaeumannomyces graminis* (Take-all), *Thielaviopsis*, and various nematodes (Behn 2008). The AM colonization can lead to quantitative and qualitative changes in the microbial community composition, and there are indications that the ERM of AM fungi supports plant growth promoting rhizobacteria (PGPR), but suppresses plant pathogens (Andrade et al. 1998). While poorly understood, several mechanisms have been proposed to explain the improved disease resistance, including:

1. Changes in the microbial community composition and an increase in the number of antagonistic microbes.
2. Reduction in the availability of nutrients for pathogens.
3. Stimulation of plant defense mechanisms.
4. Increase in plant fitness resulting from an improved nutrient supply.

### ***Effects of agricultural management practices on AM colonization***

AM fungi have the potential to reduce the required fertilizer inputs and the susceptibility to abiotic and biotic stresses, and to increase productivity and environmental sustainability of wheat production. However, agricultural management practices such as P and N fertilization, tillage or no-tillage, crop rotations, conventional or organic farming practices can affect the AM spore density in the soil and mycorrhizal colonization of food crops. It is long known that the

reliance on fertilizers to meet plant nutrient requirements can decrease the AM spore density and mycorrhizal colonization (McGonigle et al. 1990; Singh and Singh 2008).

The greater disturbance by tilling can also lead to a reduction in AM spore density and mycorrhizal colonization of crops (van Groenigen et al. 2009) and can negatively affect the AM community composition by favoring less beneficial AM species. A combination of no-tillage and crop rotations has been shown to lead to a greater richness and biodiversity of microbial communities, including AM fungi. Non-mycorrhizal preceding crops such as Brassica species have been shown to reduce the mycorrhizal colonization of wheat, whereas mycorrhizal susceptible plants such as wax flax increase the spore density and mycorrhizal colonization of wheat (Gao et al. 2009).

As a rule of thumb, AM communities and the mycorrhizal colonization of wheat can be increased by a reduced tillage intensity and application of fertilizers, by an increase in crop diversity and crop rotations particularly with mycorrhizal plants, and by using appropriate techniques to inoculate the soil with AM fungi.

## Conclusions

Mycorrhizal fungi can represent an important tool to increase the environmental sustainability of wheat production in the future with their unique effect on nutrient uptake and stress resistance. More research is needed to identify AM fungal species that provide the highest benefit for the host plant along with management practices that are able to facilitate the AM colonization and the benefit for the plant. The high colonization rates of wheat under field conditions and the impact of AM fungi on nutrient uptake strategies, indicate that the mycorrhizal responsiveness should be included as an important trait into breeding programs for nutrient-efficient and stress-resistant wheat cultivars.

## Additional information and references

- Al-Karaki, G., B. McMichael, and J. Zak. 2004. Field response of wheat to arbuscular mycorrhizal fungi and drought stress. *Mycorrhiza* 14:263-269.
- Aloui, A., G. Recorbet, F. Robert, B. Schoefs, M. Bertrand, C. Henry, V. Gianinazzi-Pearson, E. Dumas-Gaudot, and S. Aschi-Smiti. 2011. Arbuscular mycorrhizal symbiosis elicits shoot proteome changes that are modified during cadmium stress alleviation in *Medicago truncatula*. *BMC Plant Biology* 11.
- Andrade, G., R.G. Linderman, and G.J. Bethlenfalvay. 1998. Bacterial associations with the mycorrhizosphere and hyphosphere of the arbuscular mycorrhizal fungus *Glomus mosseae*. *Plant and Soil* 202:79-87.
- Azcón, R., and J.A. Ocampo. 1981. Factors affecting the vesicular-arbuscular infection and mycorrhizal dependency of thirteen wheat cultivars. *New Phytologist* 87:677-685.
- Behn, O. 2008. Influence of *Pseudomonas fluorescens* and arbuscular mycorrhiza on the growth, yield, quality and resistance of wheat infected with *Gaeumannomyces graminis*. *Journal of Plant Diseases and Protection* 115:4-8.
- Daei, G., M.R. Ardekani, F. Rejali, S. Teimuri, and M. Miransari. 2009. Alleviation of salinity stress on wheat yield, yield components, and nutrient uptake using arbuscular mycorrhizal fungi under field conditions. *J. Plant Physiology* 166:617-625.
- Gao, X., F. Akhter, M. Tenuta, D.N. Flaten, E.J. Gawalko, and C.A. Grant. 2009. Mycorrhizal colonization and grain Cd concentration of field-grown durum wheat in response to tillage, preceding crop and phosphorus fertilization. *J. Science of Food and Agriculture* 90:750-758.
- Graham, J.H., and L.K. Abbott. 2000. Wheat responses to aggressive and non-aggressive arbuscular mycorrhizal fungi. *Plant and Soil* 220:207-218.
- Hagyó, A., C. Farkas, A. Lukács, S. Csorba, and T. Németh T. 2007. Water cycle of different wheat genotypes under different water stresses. *Cereal Research Communications* 35:437-440.

Hetrick, B.A.D., G.W.T. Wilson, and T.S. Cox. 1992. Mycorrhizal dependence of modern wheat varieties, landraces, and ancestors. *Canadian J. Botany* 70:2032-2040.

Holloway, R.E., I. Bertrand, A.J. Frischke, D.M. Brace, M.J. McLaughlin, and W. Shepperd. 2001. Improving fertilizer efficiency on calcareous and alkaline soils with fluid sources of P, N, and Zn. *Plant and Soil* 236:209-219.

Johnson, N.C., J.H. Graham, and F.A. Smith. 1997. Functioning of mycorrhizal associations along the mutualism-parasitism continuum. *New Phytologist* 135:575-585.

Karamanos, R.E. 2007. *Agroeconomics of Phosphate Fertilizer in Manitoba*. 8th Annual Manitoba Agronomists Conference 2007. Cooperative Fertilizers Limited, Box 2500, Calgary AB T2P 2N1.

Li, H.Y., S.E. Smith, R.E. Holloway, Y.G. Zhu, and F.A. Smith. 2006. Arbuscular mycorrhizal fungi contribute to phosphorus uptake by wheat grown in a phosphorus-fixing soil even in the absence of positive growth responses. *New Phytologist* 172:536-543.

Li, H.Y., T.G. Zhu, P. Marschner, F.A. Smith, and S.E. Smith. 2005. Wheat responses to arbuscular mycorrhizal fungi in a highly calcareous soil differ from those of clover, and change with plant development and P supply. *Plant and Soil* 277:221-232.

McGonigle, T.P., M.H. Miller, D.G. Evans, G.L. Fairchild, and J.A. Swan. 1990. A new method which gives an objective measure of colonization of roots by vesicular-arbuscular mycorrhizal fungi. *New Phytologist* 115:495-501.

Mosali, J., K. Desta, R.K. Teal, K.W. Freeman, K.L. Martin, J.W. Lawles, and W.R. Raun. 2006. Effect of foliar application of phosphorus on winter wheat grain yield, phosphorus uptake, and use efficiency. *J. Plant Nutrition* 29:2147-2163.

Queensland Government PlaF. 2011. *Nutrition - VAM and long fallow disorder*.

Ravnkov, S., and I. Jakobsen. 1995. Functional compatibility in arbuscular mycorrhizas measured as hyphal P transport to the plant. *New Phytologist* 129: 611-618.

Schweiger, P.F., and I. Jakobsen. 1999. Direct measurement of arbuscular mycorrhizal phosphorus uptake into field-grown winter wheat. *Agronomy J.* 91:998-1002.

Sharif, M., and Nasrullah. 2009. Occurrence and distribution of arbuscular mycorrhizal fungi in wheat and maize crops of Malakand division of North West Frontier Province of Pakistan. *International J. Sustainable Agriculture* 1:24-31.

Singh, S.R., and U. Singh. 2008. Efficacy of vesicular arbuscular mycorrhizae as influenced by phosphorus application in wheat (*Triticum aestivum*) under rainfed conditions of Kashmir. *Indian J. Agricultural Sciences* 78:771-776.

Smith, F.A., E.J. Grace, and S.E. Smith. 2009a. More than a carbon economy: nutrient trade and ecological sustainability in facultative arbuscular mycorrhizal symbioses. *New Phytologist* 182:347-358.

Smith, S.E., E. Facelli, S. Pope, and F.A. Smith. 2009b. Plant performance in stressful environments: interpreting new and established knowledge of the roles of arbuscular mycorrhizas. *Plant and Soil* 326:3-20.

Tanaka, Y., and K. Yano. 2005. Nitrogen delivery to maize via mycorrhizal hyphae depends on the form of N supplied. *Plant Cell and Environment* 28:1247-1254.

van Groenigen, K.-J., J. Bloem, E. Bååth, P. Boeckx, J. Bousk, S. Bodé, D. Forristal, and M.B. Jones. 2009. Abundance, production and stabilization of microbial biomass under conventional and reduced tillage. *Soil Biology and Biochemistry* 42:48-53.

Wolnik, K.A., F.L. Fricke, S.G. Capar, G.L. Braude, and R.D. Satzger. 1983. Elements in major raw agricultural crops in the United States. 1. Cadmium and lead in lettuce, peanuts, potatoes, soybeans, sweet corn, and wheat. *Journal of Agricultural Food Chemistry* 31:1240-1244.

Zhu, Y.-G., S.E. Smith, A.R. Barritt, F.A. Smith. 2001. Phosphorus (P) efficiencies and mycorrhizal responsiveness of old and modern wheat cultivars. *Plant and Soil* 237:249-255.

#### Acknowledgements

Support for this chapter was provided by South Dakota State University and the South Dakota Wheat Commission.

Bücking, H., P. Jampani, and J. Gonzalez. 2012. Arbuscular mycorrhizal associations and their significance for wheat production. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.



## CHAPTER EIGHTEEN

# Online Web Soil Survey (WSS) Information

*Douglas D. Malo* ([Douglas.Malo@sdsu.edu](mailto:Douglas.Malo@sdsu.edu))

The purpose of this chapter is to provide a hands-on example on how to integrate Web Soil Survey (WSS) information into your operation.

### **Introduction**

In this rapidly changing world, technological advances allow us to inventory and understand soils in new and extremely useful ways. In past times, one would go to the county United States Department of Agriculture (USDA) – Natural Resources Conservation Service (NRCS) office and obtain detailed soils information from published soil surveys for a county or a selected geographic region.

Today you can obtain the same information, plus much more, online using the USDA-NRCS WSS website <http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm>, using a new application “SoilWeb: An Online Soil Survey Browser” that works with iPhone applications and Android OS smart phones <http://casoilresource.lawr.ucdavis.edu/drupal/node/902>. The WSS website is regularly updated with new options, features, and data (Fig. 18.1). Select the green button in the upper right side of the window to start the WSS application. The most recent WSS version 2.3 was released on July 25, 2011.

WSS is a powerful, user-friendly search engine for modern detailed soil survey information. The website has a detailed online tutorial to assist in using the WSS <http://websoilsurvey.nrcs.usda.gov/app/Help/FrequentlyAskedQuestions.htm#help>. There are other sources that provide additional WSS instructions (Malo 2008). This chapter provides basic information in how to obtain basic soil maps, soil productivity ratings, yields, and other soil information using WSS.



Click here to start WSS

**Figure 18.1. Web Soil Survey (WSS) home page.**  
<http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm>

### *On-line sources of land and soils information*

There are many sources of land and soil data available online. Table 18.1 shows a partial listing of useful websites for producers, agronomists, and natural resource managers. This table is not meant to be all-inclusive, but rather attempts to identify selected information sources.

### *Web Soil Survey*

Web Soil Survey is widely used by farmers, ranchers, natural resource managers, and planners. This online interactive site is user friendly and is a powerful tool for both visual and tabular information. Please check the online requirements for WSS to make sure your computer system is configured to allow this interactive program to operate. <http://websoilsurvey.nrcs.usda.gov/app/Help/Requirements.htm>

This section will briefly describe how you can use WSS. Before selecting an Area of Interest (AOI), you need to make sure the WSS system has the modern soil survey data available for your county. Check the status of the soil data available by county by visiting the most recent status map at <http://soildatamart.nrcs.usda.gov/StatusMaps/SoilDataAvailabilityMap.pdf>.

There are three basic steps in using WSS.

1. Identify and define the AOI where you need to obtain detailed soil information. This area can be a field, farm, or parcel of land. The AOI in this program is limited to 10,000-acre size limit. Other questions dealing with the AOI and operation of WSS are available at <http://websoilsurvey.nrcs.usda.gov/app/Help/FrequentlyAskedQuestions.htm>.
2. Once the AOI is identified, the soils map is prepared and you can assess the suitability and limitations of soils for selected uses. Maps and tables of selected soil physical/chemical properties and characteristics as well as land productivity information are available.
3. Electronically store and/or print the available data generated by the WSS session using the Shopping Cart Tab and Check-out Option.



**Table 18.1. Online sources of soils and natural resources information. (continues on next page)**

<b>Name</b>	<b>Information Available</b>	<b>Web address (verified 28 July 2011)</b>
Agricultural Research Service, USDA	Home page, research results and projects	<a href="http://www.ars.usda.gov/main/main.htm">http://www.ars.usda.gov/main/main.htm</a>
American Fact Finder (U.S. Census Bureau)	Source of population, housing, economic, and geographic data by town, county, or zip code area	<a href="http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml">http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml</a>
Bureau of Land Management, USDOl	Home page, projects and activities	<a href="http://www.blm.gov/wo/st/en.html">http://www.blm.gov/wo/st/en.html</a>
California Soil Resource Lab	Soil Survey Data	<a href="http://casoilresource.lawr.ucdavis.edu/drupal/node/902">http://casoilresource.lawr.ucdavis.edu/drupal/node/902</a>
Canada Centre for Remote Sensing	General remote sensing information	<a href="http://ccrs.nrcan.gc.ca/index_e.php">http://ccrs.nrcan.gc.ca/index_e.php</a>
Current Research Information System (CRIS)	Current agricultural research results and publications	<a href="http://cris.nifa.usda.gov/">http://cris.nifa.usda.gov/</a>
EROS Data Center (USGS)	Home page, satellite and aerial images, research projects and programs	<a href="http://eros.usgs.gov/">http://eros.usgs.gov/</a>
Google Maps/ Google Earth	Various maps of U.S. in 2 and 3 dimensions	<a href="http://maps.google.com/">http://maps.google.com/</a> <a href="http://www.google.com/earth/index.html">http://www.google.com/earth/index.html</a>
Map Stats of U.S.	Federal statistics maps for state, county, and city	<a href="http://www.fedstats.gov/qf/">http://www.fedstats.gov/qf/</a>
National Agricultural Statistics Service	Agricultural statistics for state and county	<a href="http://www.nass.usda.gov/">http://www.nass.usda.gov/</a>
National Information Management and Support System (NIMSS)	Agricultural research activities and projects in the state, region, and nation	<a href="http://nimss.umd.edu/">http://nimss.umd.edu/</a>
National Institute of Food and Agriculture (NIFA)	Home page and agricultural research information	<a href="http://www.csrees.usda.gov/">http://www.csrees.usda.gov/</a>
National Map Viewer (USGS)	Various kinds and scales of U.S. maps	<a href="http://nationalmap.gov/viewers.html">http://nationalmap.gov/viewers.html</a>
NRCS – Field Office Technical Guide	Provide county specific scientific technical and reference information on soil, water, air, plant and animal conservation	<a href="http://www.nrcs.usda.gov/technical/efotg/">http://www.nrcs.usda.gov/technical/efotg/</a>
NRCS – Hydric Soils	Hydric soils information	<a href="http://soils.usda.gov/use/hydric/">http://soils.usda.gov/use/hydric/</a>
NRCS – Major Land Resource Areas (MLRAs)	Physiography, geology, climate, water resources, soils, biological resources, and kinds of land use	<a href="http://soils.usda.gov/survey/geography/mlra/index.html">http://soils.usda.gov/survey/geography/mlra/index.html</a>
NRCS – National Soil Survey Handbook	Technical guide for soil survey projects and activities	<a href="http://soils.usda.gov/technical/handbook/">http://soils.usda.gov/technical/handbook/</a>
NRCS – National Range and Pasture Handbook	Procedures for the inventory, analysis, treatment, and management of grazing land resources	<a href="http://www.glti.nrcs.usda.gov/technical/publications/nrph.html">http://www.glti.nrcs.usda.gov/technical/publications/nrph.html</a>
NRCS – National Centers	National NRCS Centers (e.g., Water + Climate, Soil Survey, Agroforestry, and others)	<a href="http://www.nrcs.usda.gov/about/organization/cent_in st.html">http://www.nrcs.usda.gov/about/organization/cent_in st.html</a>

**Table 18.1. Online sources of soils and natural resources information.**

NRCS – National Water and Climate Center	Climate and water conservation planning information	<a href="http://www.wcc.nrcs.usda.gov/">http://www.wcc.nrcs.usda.gov/</a>
NRCS – Offices/Centers	State and county office location and address information	<a href="http://www.nrcs.usda.gov/about/organization/regions.html">http://www.nrcs.usda.gov/about/organization/regions.html</a>
NRCS – Official Soil Series Descriptions	Detailed, official soil series descriptions for soils in US	<a href="http://soils.usda.gov/technical/classification/osd/index.html">http://soils.usda.gov/technical/classification/osd/index.html</a>
NRCS – Soil Data Mart	Soil physical, chemical, and characterization data	<a href="http://soildatamart.nrcs.usda.gov/">http://soildatamart.nrcs.usda.gov/</a>
NRCS – Soil Quality	Soil quality definition, assessment, management, resources, and publications	<a href="http://soils.usda.gov/sqi/">http://soils.usda.gov/sqi/</a>
NRCS – Soil Survey Manual	Soil Survey Manual Publication	<a href="http://soils.usda.gov/technical/manual/">http://soils.usda.gov/technical/manual/</a>
NRCS - Soils	Home page, soil classification, lab data	<a href="http://soils.usda.gov/">http://soils.usda.gov/</a>
NRCS – Technical References	Web site for manuals, technical guides, and references used by NRCS	<a href="http://soils.usda.gov/technical/">http://soils.usda.gov/technical/</a>
NOAA	Weather data, drought monitoring, current conditions	<a href="http://www.weather.gov/">http://www.weather.gov/</a>
Service Center Locator (USDA)	Service Center locator and contact information	<a href="http://offices.sc.egov.usda.gov/locator/app">http://offices.sc.egov.usda.gov/locator/app</a>
Site Specific Management Guide	Site specific management for agriculture	<a href="http://www.ipni.net/e-catalog/SSMG/ssmg.htm">http://www.ipni.net/e-catalog/SSMG/ssmg.htm</a>
Soil Orders	Images of 12 soil orders	<a href="http://soils.cals.uidaho.edu/soilorders/">http://soils.cals.uidaho.edu/soilorders/</a>
US Forest Service	Home page	<a href="http://www.fs.fed.us/">http://www.fs.fed.us/</a>
Web Soil Survey (WSS)	Detailed soil survey information	<a href="http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm">http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm</a>
World Reference Base for Land Resources	Soil classification and soil description for world – FAO	<a href="http://www.fao.org/nr/land/soils/soil/en/">http://www.fao.org/nr/land/soils/soil/en/</a>

### ***Step 1 – Define Area of Interest (AOI)***

The first step in using WSS is to identify your AOI. The AOI is used by the WSS to generate tabular and visual data for use in later steps of the WSS. The AOI can be located either by using the various Quick Navigation options or the Interactive Map option (Fig. 18.2) in the WSS Navigation window. When using the Quick Navigation option, you can locate your AOI by entering any **one** of the following:

1. Local street address.
2. State and county identification.
3. Longitude and latitude.
4. Legal land description (section, town, and range). Remember to select the proper Principal Meridian (PM) for your AOI. Use the drop-down helps in the program to assist you in picking the proper PM (Fig. 18.3).
5. Other (Bureau of Land Management Field Office [BLM], Defense Department Installation [DOD], U.S. Forest Service [USFS], National Park Service [NPS], or Hydrologic Unit [HU] Code [8 digit code]).



Use the Interactive Map option on the entry page to find your AOI if you do not have information for one of the options (1-5) listed above.

Once the AOI has been located, the boundaries of the AOI need to be entered into the WSS application. Select one of the two boundary buttons. The left button allows you to identify the AOI boundaries using a rectangular box, while the right button allows you to use polygons (Fig. 18.3). Once you have outlined the AOI, then double click to electronically define and enter the AOI into WSS. After the AOI is defined and accepted, the acres and availability of soils data/maps and an air photo of the AOI are given (Fig. 18.4).

### ***Step 2a – Soils map for AOI***

After completion of Step 1 (AOI defined), you then click on the Soil Map tab at the top of the WSS Web page to create a modern detailed soil survey map for the AOI (Fig. 18.5). The types of information available include: the soil map and legend (tab on upper left side of image), the soil map unit (MU) name and symbol, number of acres of each soil MU, the percentage of AOI that each soil MU occupies, and tabular data for each MU. The tabular data (click on the MU name found in the AOI in the dropdown box on the left side of the Soil Map window, Fig. 18.6) includes:

1. *MU setting* – elevation, annual precipitation, average annual temperature, and frost-free days.
2. *MU composition* – lists all the major and minor soil units with their composition %.
3. *Description of each major MU component* (named in the MU name).
  - a. Setting for named series – landform, landscape position, slope shape (down and across), and parent material.
  - b. Selected soil properties and qualities – % slope, restrictive layers, drainage class, permeability, depth to water table, flooding and ponding frequency, lime (calcium carbonate content), salinity (EC), sodium adsorption ratio (SAR), and profile plant available water holding capacity.
  - c. Interpretive groups – Land Capability Classification, Ecological Site (formerly Range Site), and Other Vegetative Groups (e.g., Forage Suitability Groups),
  - d. Typical profile information (e.g., horizon depths and textures).
4. *A brief description of each minor MU component* to explain how the minor soil differs from the named major MU component(s).

If you would like a copy of the soil map or include the soil map in a custom soil survey report, select the proper print tab in the upper right-hand corner of the window (Fig. 18.7). There are two options, Printable Version or Add to Shopping Cart. The Printable Version option allows you to download a pdf version of just the soil map and associated documentation.

The Add to Shopping Cart option adds the soil map to a file and saves the file until you are done with your WSS session. You can then print out a customized Web-based soil survey report including the soil map with other maps and tables you need. Note that when either the Printable Version or the Add to Shopping Cart button is selected, it will fade.

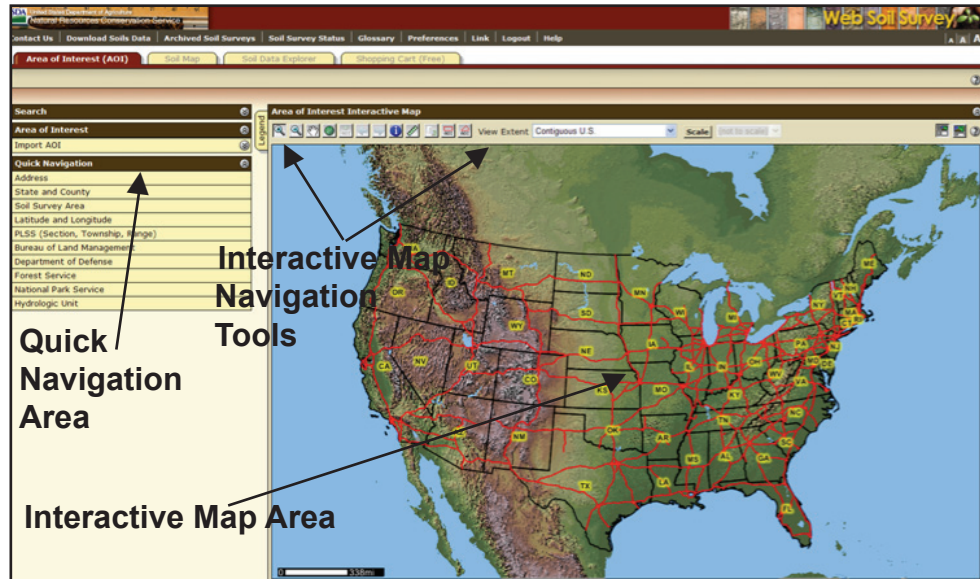
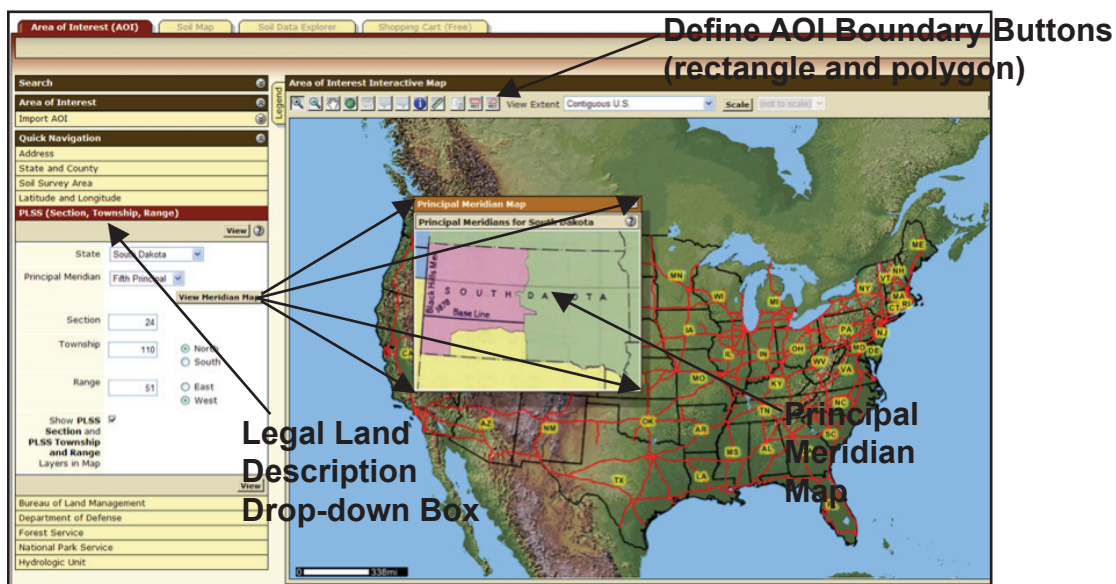


Figure 18.2. WSS Area of Interest selection window with quick navigation and interactive map options.  
<http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>

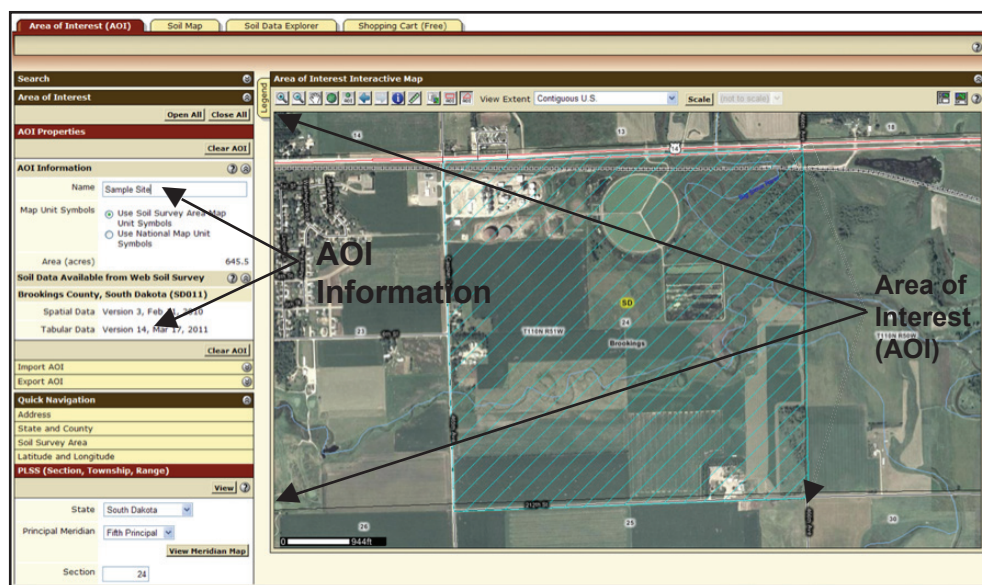
### ***Step 2b – Soil suitabilities/limitations/properties and characteristics for AOI***

To look at various soil properties, qualities, and uses (Suitabilities and Limitations), select the Soil Data Explorer tab at the top of the Web page (Fig. 18.8). A new window appears giving you the options of:

1. Intro to Soils (tutorial about soils and their use).
2. Suitabilities and Limitations for Use.
3. Soil Properties and Qualities.
4. Ecological Site Assessment.
5. Soil Reports.



**Figure 18.3.** Using WSS legal land description quick navigation tool for locating area of interest (AOI). Principal Meridian drop-down box is located in center of the window. Example – Eastern South Dakota uses the Fifth Principal Meridian for legal land description.



**Figure 18.4.** WSS Area of Interest (AOI) selection window with AOI defined (cross-hatched).

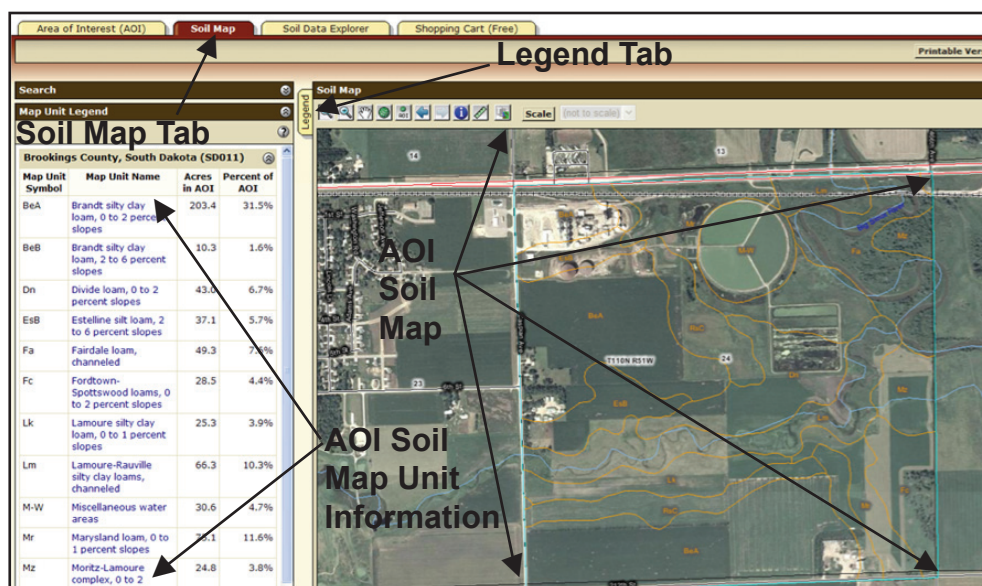


Figure 18.5. WSS Soil Map for Area of Interest (AOI) information.

Select the Suitabilities and Limitations for Use tab. A new series of dropdown tabs appears on the left side of the Web page window (Fig. 18.8). If you press the Open All tab, then all the options for each category (e.g., Land Classification, Sanitary Facilities, Vegetative Productivity, etc.) in the box will open.

The categories of Land Classification, Land Management, Vegetative Productivity, Waste Management, and Water Management are most commonly used for agricultural production and management decisions (Table 18.2).

Spring wheat yield data (rating map, legend and description) for the AOI can be seen in Figures 18.9 and 18.10. For each soil suitability or limitation listed, you can look at the dominant condition within a MU, the dominant soil in a MU, all components of a MU, components of a certain percentage, or a weighted average of all components in a MU.

You can print/save a single purpose map, associated legend, description information, and other related materials by using the Printable Version tab or Add to Shopping Cart tab in the upper right hand of the Web page window. Note that the tabs in the Add to Shopping Cart area fade when selected. When the report becomes large (>8 MB), the NRCS will send you the report by email as a pdf file after it is created.

In addition to soil suitabilities and limitations for land use, there is a tab for Soil Properties and Qualities at the top of the Web page (Fig. 18.11). If you select this tab, a drop-down box with various categories (chemical, erosion, physical, and water) of soil properties and qualities appears on the left side of the window.

For each soil property or quality selected, you can look at the dominant condition within a MU, the dominant soil in a MU, all components of a MU, components of a certain percentage, or a weighted average of all components in a MU. You also can select the soil depth range, e.g., surface, part of a profile, or all of a profile (Advanced Options, Fig. 18.12). Many different options are available for viewing maps (Fig. 18.13) and tables (Fig. 18.14 and Table 18.3).

For water table information, you can select the months when excess water is a problem. You can print and/or electronically save a single purpose map, associated legend, description information, and other related materials by using the Printable Version tab or Add to Shopping Cart tab in the upper right hand of the Web page window.



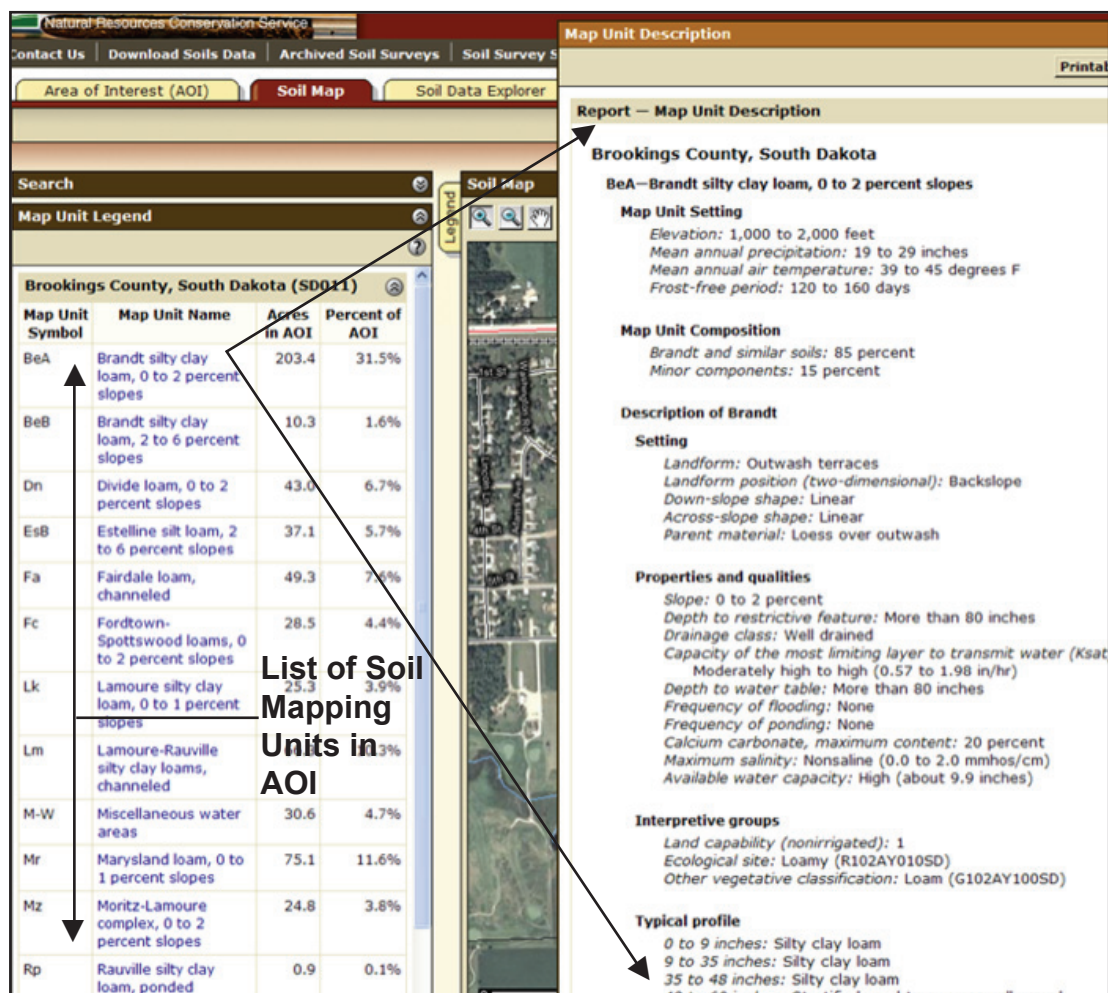


Figure 18.6. Sample WSS map unit information (obtained by clicking on the soil mapping unit name, e.g., Brandt silty clay loam).

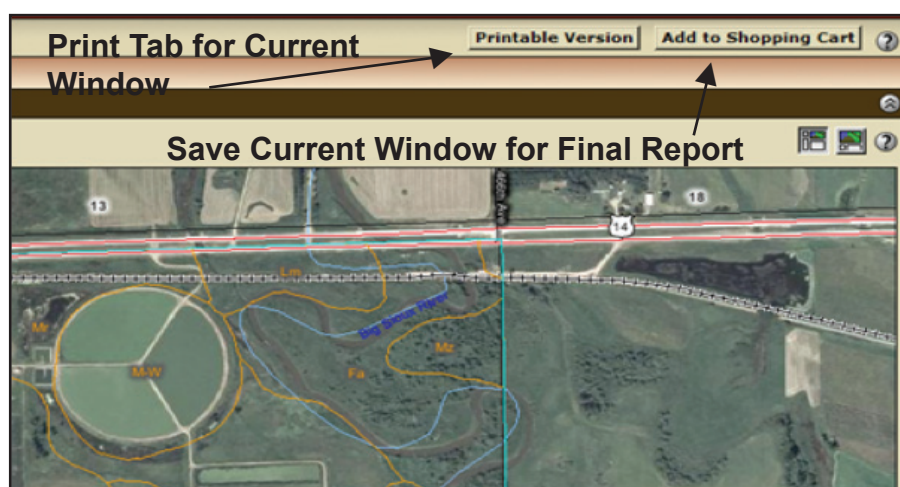
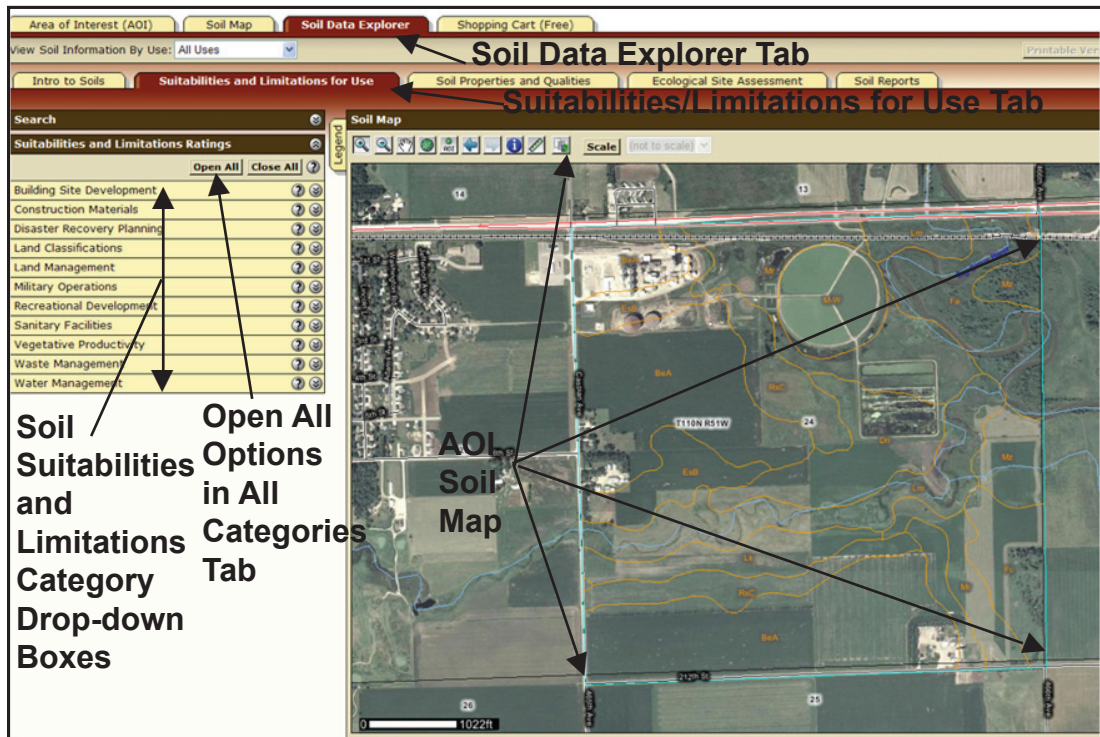


Figure 18.7. Location of Printable Version tab and Add to Shopping Cart tab in upper right-hand corner of WSS window. Printable Version tab creates a pdf file of the current window on the computer monitor and the Add to Shopping Cart tab stores the current window contents and associated information for later retrieval in a final report.



**Figure 18.8.** WSS suitabilities and limitations for use window with drop-down boxes on the left. If you want all options to be visible in the drop-down area, select the Open All tab.

**Table 18.2.** Selected WSS suitability and limitation category information available for agricultural purposes. (continues on next page)

WSS Suitability/Limitation Category*	Category Options*	Explanation/Examples
Land Classifications	Tree and Shrub Groups	Lists trees/shrubs best suited for MU
	Ecological Site ID and Name	Forage Suitability Groups and Rangeland Sites
	Farmland Classification	Identifies if land in prime farmland, land of state importance, land of local importance, unique land, or land not prime or of importance
	Hydric Rating	The components of each soil mapping unit are evaluated for hydric criteria and the map unit is designated as all hydric, partially hydric, not hydric, or unknown
	Dryland Land Capability Class and Subclass (irrigated where available)	Soil limitations for crop, grass (range), and timber production
	Soil Taxonomy Classification	Soil classification based on Soil Taxonomy
Land Management	Erosion Hazard (Off-Road, Off Trail)	Soil loss from off-road and off trail areas disturbance
	Erosion Hazard (Road, Trail)	Soil loss from unsurfaced roads and trails
	Fugitive Dust Resistance	Vulnerability of soil to go into suspension during a wind storm
	Potential for Fire Damage	Rating of potential fire damage to nutrient, physical, and biological soil properties/quality

**Table 18.2. Selected WSS suitability and limitation category information available for agricultural purposes.**

<b>WSS Suitability/Limitation Category*</b>	<b>Category Options*</b>	<b>Explanation/Examples</b>
Land Management ( <i>continued</i> )	Soil Degradation Susceptibility	Susceptibility for soil degradation during disturbance on rangeland or woodland
	Soil Restoration Potential	Soil's inherent ability to recover from degradation (soil resilience)
	Suitability for Roads (Natural Surface)	Soil suitability for natural road surface
Sanitary Facilities	Septic Tank Absorption Fields	Soil between 24 to 60 inches evaluated for use in septic tank absorption fields
	Sewage Lagoon	Identify the soil feature and extent to which soils are limited by soil features impacting sewage lagoon construction and function
Vegetative Productivity	Crop Productivity Index	Relative ranking of soils based on intensive crop production potential (not crop specific)
	Forest Productivity	Tree Site Index and cubic feet of wood/acre/year
	Range Production	Amount of vegetation expected in favorable, normal, and unfavorable years in a well-managed area supporting a native plant community
	Yields of Irrigated Crops (by Component or Map Unit)	Crop yields for selected crops suited to a county are presented (e.g., alfalfa hay, barley, bromegrass hay, bromegrass-alfalfa hay, corn, corn silage, grain sorghum, oats, soybeans, spring wheat, sunflowers, and winter wheat)
	Yields of Non-Irrigated Crops (by Component or Map Unit)	Crop yields for selected crops suited to a county are presented (e.g., alfalfa hay, barley, bromegrass hay, bromegrass-alfalfa hay, corn, corn silage, grain sorghum, oats, soybeans, spring wheat, sunflowers, and winter wheat)
Waste Management	Manure and Food Waste Management	Soil properties and features rated based on their impact on agricultural waste management
Water Management	Excavated Ponds (Aquifer fed)	Soil suitability for excavated dugouts/pits to provide water from a groundwater aquifer/water table

*\*Please note that not all WSS Suitability/Limitation categories or all options within a category are listed in this table. Some items listed in this table may not be available in all counties and different items of local importance may be present.*



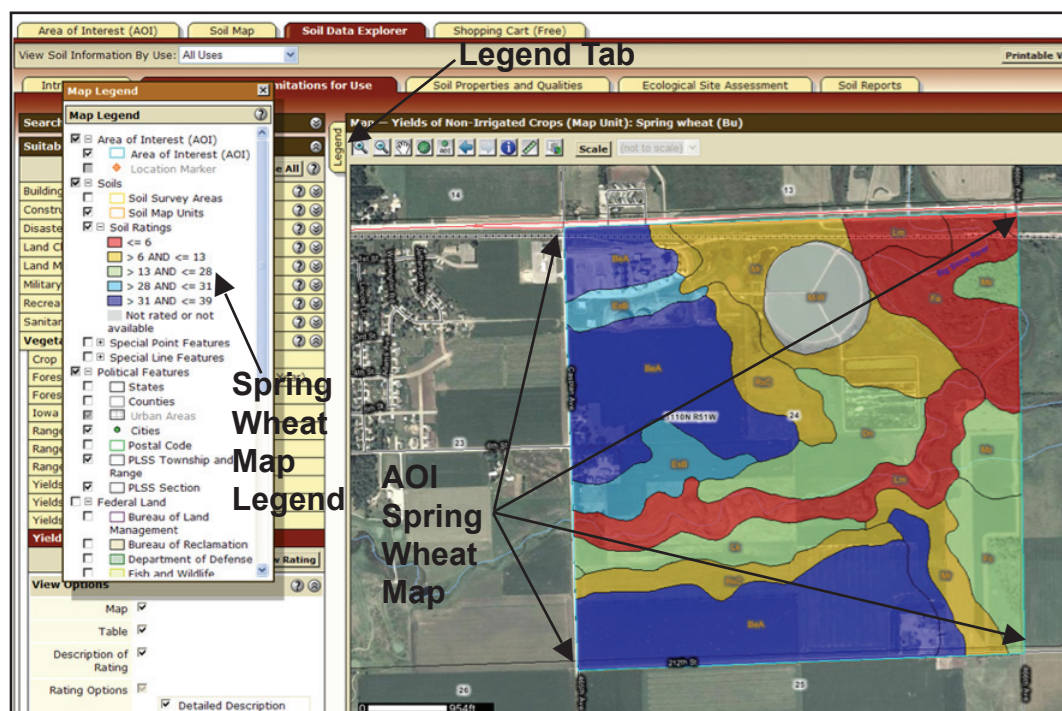


Figure 18.9. Sample WSS Soil Data Explorer window Suitabilities and Limitations for Use tab (estimated spring wheat yields (bu/a) for Area of Interest (AOI), right, and Legend on the left. Note: click the Legend tab to cause the suitability map legend to appear.

Tables — Yields of Non-Irrigated Crops (Map Unit): Spring wheat (Bu) — Summary By Map Unit				
Summary by Map Unit — Brookings County, South Dakota (SD011)				
Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
BeA	Brandt silty clay loam, 0 to 2 percent slopes	39.00	203.4	31.5%
BeB	Brandt silty clay loam, 2 to 6 percent slopes	36.00	10.3	1.6%
Dn	Divide loam, 0 to 2 percent slopes	28.00	43.0	6.7%
EsB	Estelline silt loam, 2 to 6 percent slopes	31.00	37.1	5.7%
Fa	Fairdale loam, channeled	6.00	49.3	7.6%
Fc	Fordtown-Spottswood loams, 0 to 2 percent slopes	28.00	28.5	4.4%
Lk	Lamoure silty clay loam, 0 to 1 percent slopes	26.00	25.3	3.9%
Lm	Lamoure-Rauville silty clay loams, channeled	6.00	66.3	10.3%
M-W	Miscellaneous water areas		30.6	4.7%
Mr	Marysland loam, 0 to 1 percent slopes	13.00	75.1	11.6%
Mz	Montz-Lamoure complex, 0 to 2 percent slopes	26.00	24.8	3.8%
Rp	Rauville silty clay loam, ponded	1.00	0.9	0.1%
RSC	Renshaw-Sioux complex, 6 to 9 percent slopes	11.00	50.9	7.9%
<b>Totals for Area of Interest</b>			<b>645.5</b>	<b>100.0%</b>
Description — Yields of Non-Irrigated Crops (Map Unit)				
<p>These are the estimated average yields per acre that can be expected of selected nonirrigated crops under a high level of management. In any given year, yields may be higher or lower than those indicated because of variations in rainfall and other climatic factors.</p> <p>In the database, some states maintain crop yield data by individual map unit component and others maintain the data at the map unit level. Attributes are included in this application for both, although only one or the other is likely to contain data for any given geographic area. This attribute uses data maintained at the map unit level.</p> <p>The yields are actually recorded as three separate values in the database. A low value and a high value indicate the range for the soil component. A "representative" value indicates the expected value for the component. For these yields, only the representative value is used.</p> <p>The yields are based mainly on the experience and records of farmers, conservationists, and extension agents. Available yield data from nearby areas and results of field trials and demonstrations also are considered.</p> <p>The management needed to obtain the indicated yields of the various crops depends on the kind of soil and the crop. Management can include drainage, erosion control, and protection from flooding; the proper planting and seeding rates; suitable high-yielding crop varieties; appropriate and timely tillage; control of weeds, plant diseases, and harmful insects; favorable soil reaction and optimum levels of nitrogen, phosphorus, potassium, and trace elements for each crop; effective use of crop residue, barnyard manure, and green manure crops; and harvesting that ensures the smallest possible loss.</p> <p>The estimated yields reflect the productive capacity of each soil for the selected crop. Yields are likely to increase as new production technology is developed. The productivity of a given soil compared with that of other soils, however, is not likely to change.</p>				

Figure 18.10. Sample WSS Soil Data Explorer yield table and descriptive information for spring wheat map created in Figure 18.9. This information is located under (scroll down) the yield map.

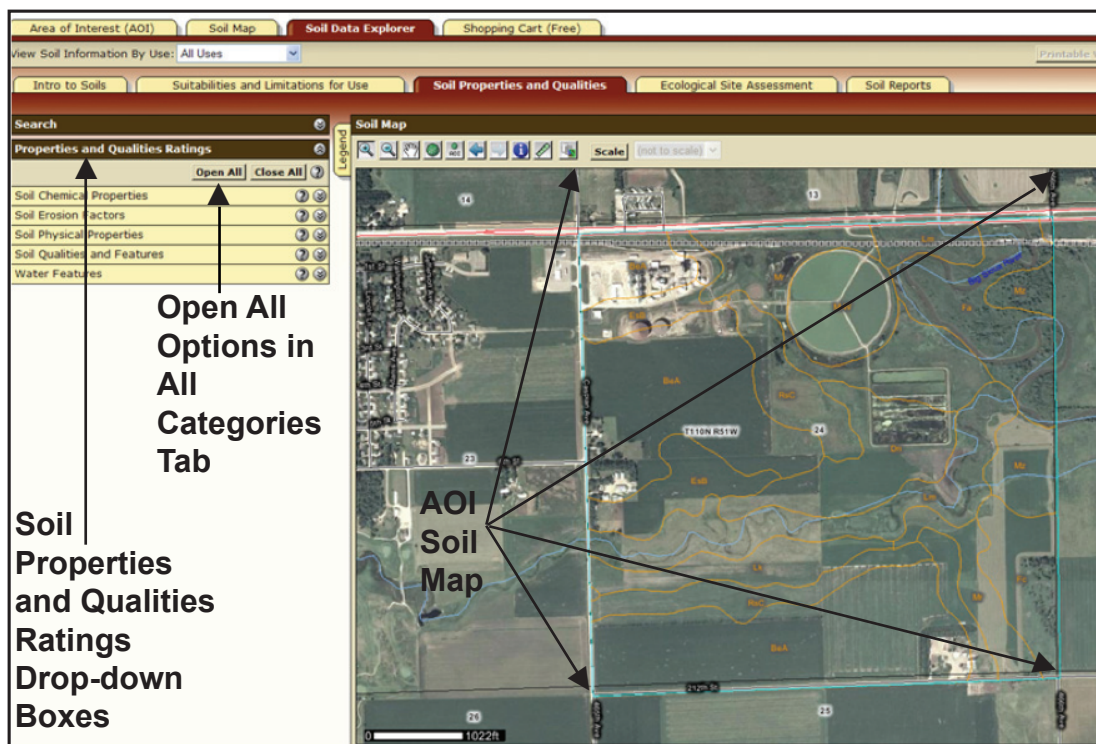


Figure 18.11. WSS Soil Properties and Qualities window with drop-down boxes on the left. If you want all options to be visible in the drop-down area, select the Open All tab.

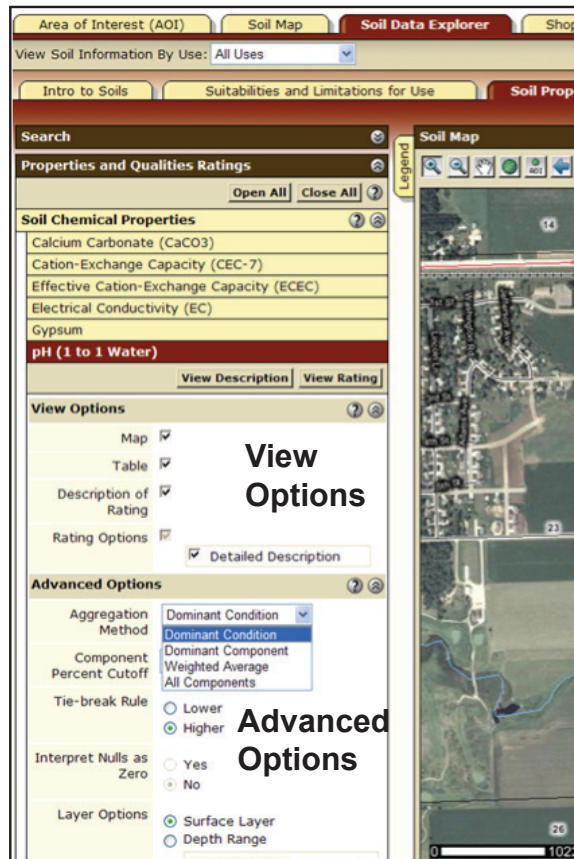


Figure 18.12. WSS View Options and Advanced Options for soil properties and qualities for drop-down boxes in Soil Properties and Qualities window.



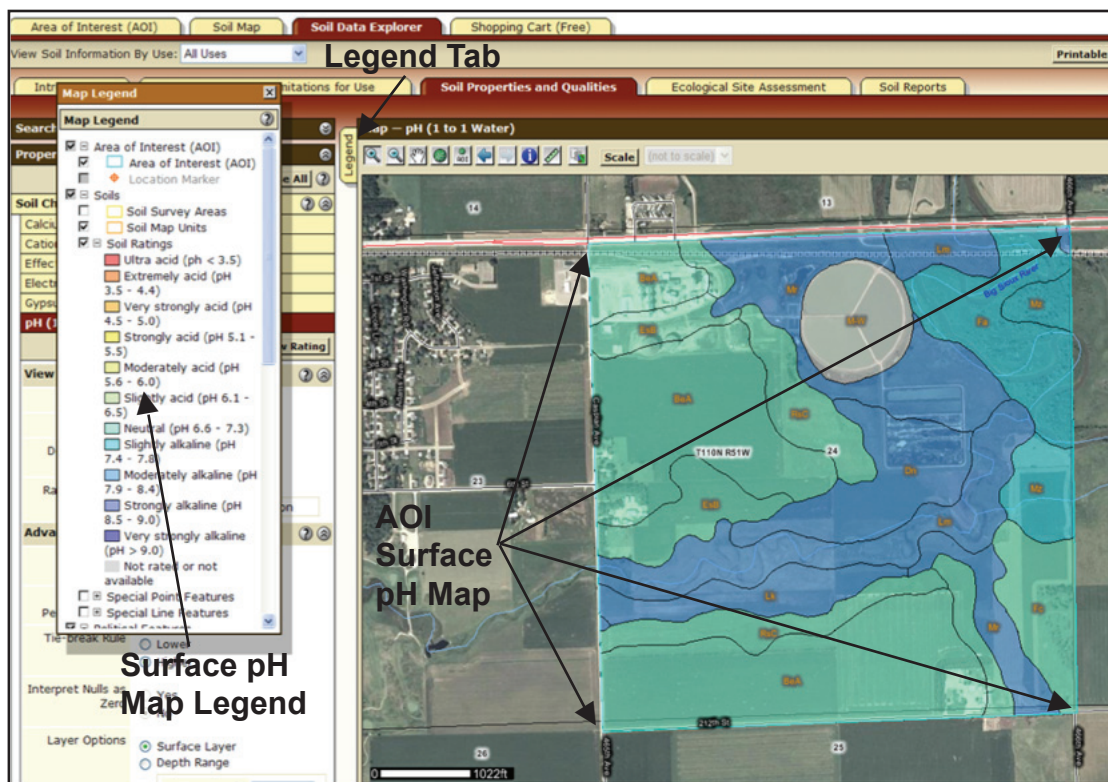


Figure 18.13. Sample WSS Soil Data Explorer window – Soil Properties and Qualities tab (Surface Soil pH) for Area of Interest (AOI), right, and Legend on the left. Note: click the Legend tab to cause the soil property map legend to appear.

Tables — pH (1 to 1 Water) — Summary By Map Unit					
Summary by Map Unit — Brookings County, South Dakota (SD011)					
Map unit symbol	Map unit name	Rating	Acres in AOI		Percent of AOI
BeA	Brandt silty clay loam, 0 to 2 percent slopes	6.7	203.4	31.5%	
BeB	Brandt silty clay loam, 2 to 6 percent slopes	6.7	10.3	1.6%	
Dn	Divide loam, 0 to 2 percent slopes	7.9	43.0	6.7%	
EsB	Estelline silt loam, 2 to 6 percent slopes	6.7	37.1	5.7%	
Fa	Fairdale loam, channeled	7.6	49.3	7.6%	
Fc	Fordtown-Spottswood loams, 0 to 2 percent slopes	6.7	28.5	4.4%	
Lk	Lamoure silty clay loam, 0 to 1 percent slopes	7.9	25.3	3.9%	
Lm	Lamoure-Rauville silty clay loams, channeled	7.9	66.3	10.3%	
M-W	Miscellaneous water areas		30.6	4.7%	
Mr	Marysland loam, 0 to 1 percent slopes	8.2	75.1	11.6%	
Mz	Moritz-Lamoure complex, 0 to 2 percent slopes	7.5	24.8	3.8%	
Rp	Rauville silty clay loam, ponded	7.9	0.9	0.1%	
RsC	Renshaw-Sioux complex, 6 to 9 percent slopes	7.0	50.9	7.9%	
<b>Totals for Area of Interest</b>			<b>645.5</b>	<b>100.0%</b>	
Description — pH (1 to 1 Water)					
Soil reaction is a measure of acidity or alkalinity. It is important in selecting crops and other plants, in evaluating soil amendments for fertility and stabilization, and in determining the risk of corrosion. In general, soils that are either highly alkaline or highly acid are likely to be very corrosive to steel. The most common soil laboratory measurement of pH is the 1:1 water method. A crushed soil sample is mixed with an equal amount of water, and a measurement is made of the suspension.					
For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.					

Figure 18.14. Sample WSS Soil Data Explorer soil properties and qualities ratings and descriptive information for surface pH for map created in Figure 18.13. This information is located under (scroll down) the pH map.

**Table 18.3. Selected WSS soil properties and qualities information available for agricultural purposes.**  
(continues on next page)

WSS Soil Properties and Qualities Category*	Category Options*	Explanation/Examples
Soil Chemical Properties	Calcium Carbonate (CaCO <sub>3</sub> - Lime)	Percent calcium carbonate by weight in the <2mm size fraction.
	Cation Exchange Capacity (CEC-7)	Total amount of extractable cations that can be held by soil at pH 7.
	Electrical Conductivity (EC)	Conductivity of a saturated paste extract (mmhos/cm) – measure of water soluble salt concentration in soils.
	Gypsum	Pct gypsum by weight in the <2 mm size fraction.
	pH (1:1 Water)	Measure of acidity and alkalinity using 1 part water and 1 part soil (weight basis).
	Sodium Adsorption Ratio (SAR)	Measure of the amount of sodium (Na <sup>+</sup> ) relative to the calcium + magnesium (Ca <sup>2+</sup> +Mg <sup>2+</sup> ) in a saturated soil paste extract.
Soil Erosion Factors	K Factor	Soil susceptibility to sheet and rill water erosion.
	T Value	Maximum tolerated amount of wind and water erosion without reducing productivity.
	Wind Erodibility Group/Index	Soil properties affecting soil susceptibility to wind erosion, index-numerical value indicating susceptibility to wind and water erosion.
Soil Physical Properties	Available Water Holding Capacity	Amount of plant available water in the 0-25, 0-50, 0-100, and 150 cm depths.
	Bulk Density	Soil bulk density at 15, 1/10, and 1/3 bars are used to calculate shrink-swell potential, plant available water holding capacity, total pore space, and other soil properties. The soil bulk density indicates the pore space available for water and roots.
	% Organic Matter	Organic matter is decomposed and decomposing plant and animal residue in the soil. Organic matter content is determined on the soil particles <2 mm and is % by weight.
	% Sand, % Clay, % Silt	The percent of each soil separate by weight <2 mm in diameter sized soil materials.
	Saturated Hydraulic Conductivity or permeability (K <sub>sat</sub> )	Transmission rate (ease) with which saturated soil pores allow water to move or pass through.
	Surface Texture	Representative soil textural class, plus any appropriate coarse fragment modifiers.
	Water Content at 1/3 and 15 bars	Volumetric water content at 1/3 bar (field capacity) and 15 bar (wilting point) are used to define plant available water (=1/3 - 15 bar).
Soil Qualities and Features	Depth to Any Soil Restrictive Layer	Depth to soil layer that significantly impedes root growth and/or water and air movement.
	Drainage Class	Frequency and duration of wet period that are expressed in the morphology of the soil.

**Table 18.3. Selected WSS soil properties and qualities information available for agricultural purposes.**

WSS Soil Properties and Qualities Category*	Category Options*	Explanation/Examples
Water Features	Depth to Water Table	Water table refers to a saturated zone in the soil present long enough (1 month or more) to cause significant changes in soil properties and management. User defines the months to use. Depths are determined based on observed water table measurements and based on the presence of redox features (gray colors) in the soil.
	Flooding Frequency	Temporary inundation caused by overflowing streams or runoff from adjacent slopes. Water standing for short periods after rainfall or snowmelt is not considered flooding, and water standing in closed depressions (e.g., prairie potholes/wetlands, swamps, and marshes) is considered ponding rather than flooding.
	Ponding Frequency	Water standing in closed depressions (e.g., prairie potholes/wetlands, marshes, and others). Water is only lost through evaporation, transpiration, and deep percolation.

*\*Please note that not all WSS Properties and Qualities categories or all options within a category are listed in this table. Some items listed in this table may not be available in all counties and different items of local importance may be present.*

The fourth tab in the Soil Data Explorer window, Ecological Site Assessment, provides Ecological Site information (Fig. 18.15). This information includes an ecological site assessment map and associated tabular data for the AOI, viz., MU name, MU components (% of MU), and Ecological Site ID for each component, and detailed information about each ecological site (Fig. 18.16).

The ecological site information for rangeland is available. For selected counties, ecological sites for pasture groups are also given. The types of information given for a rangeland ecological site include: a photo of the plant communities, a brief ecological site description and impacts of management on species (composition and abundance), and a transition diagram illustrating the impact of management on the plant communities in the ecological site (Fig.18.17). Within each ecological site, various plant communities are further explained (e.g., community description, management impacts, production total, species identification, species productivity, and plant growth curves) relative to the impact of management on plant communities in this Ecological Site (Fig. 18.18).

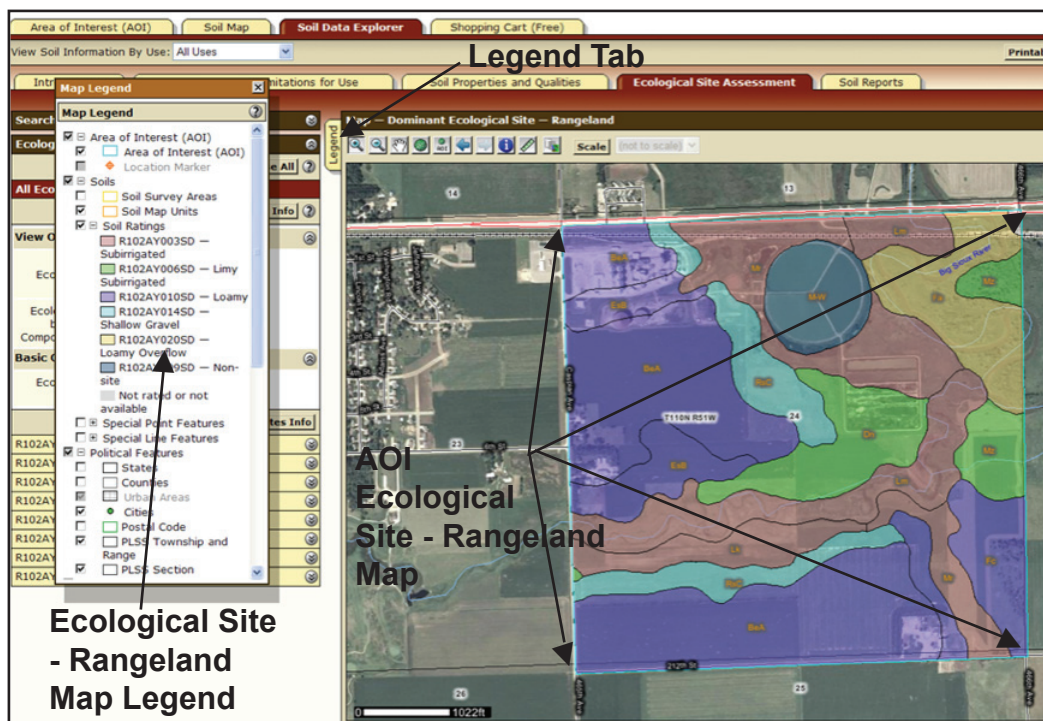
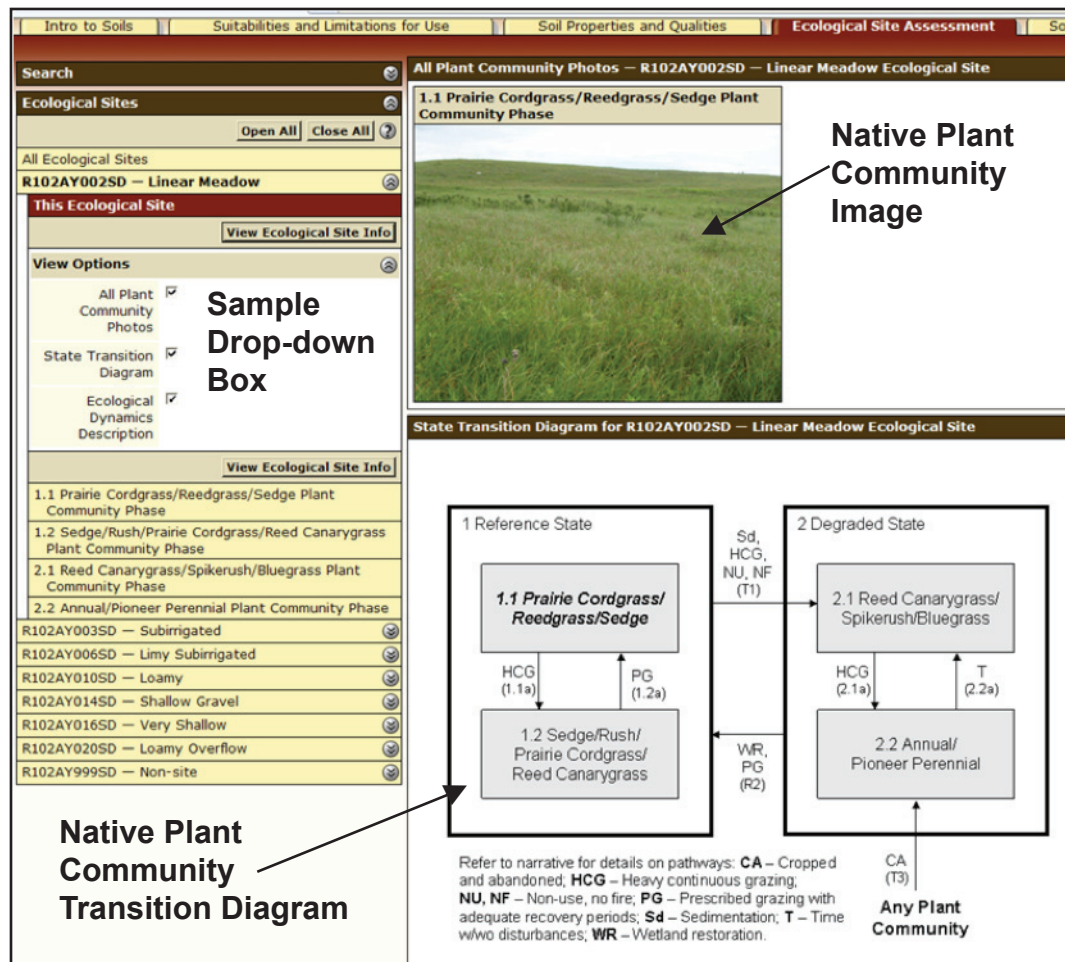


Figure 18.15. Sample WSS Soil Data Explorer window Ecological Site Assessment tab (Dominant Ecological Site-Rangeland) for Area of Interest (AOI), right, and Legend on left. Note: click the Legend tab to cause the Ecological Site - Rangeland map legend to appear.

Map unit symbol	Map unit name	Component name (percent)	Ecological site	Acres in AOI	Percent of AOI
BeA	Brandt silty clay loam, 0 to 2 percent slopes	Brandt (85%)	R102AY010SD — Loamy	203.4	31.5%
		Estelline (8%)	R102AY010SD — Loamy		
		Goldsmith (5%)	R102AY020SD — Loamy Overflow		
		Badger (1%)	R102AY020SD — Loamy Overflow		
		Poinsett (1%)	R102AY010SD — Loamy		
BeB	Brandt silty clay loam, 2 to 6 percent slopes	Brandt (85%)	R102AY010SD — Loamy	10.3	1.6%
		Estelline (8%)	R102AY010SD — Loamy		
		Goldsmith (5%)	R102AY020SD — Loamy Overflow		
		Badger (1%)	R102AY020SD — Loamy Overflow		
		Poinsett (1%)	R102AY010SD — Loamy		
On	Divide loam, 0 to 2 percent slopes	Divide (85%)	R102AY006SD — Limy Subirrigated	43.0	6.7%
		Marysland, undrained (9%)	R102AY003SD — Subirrigated		
		Fordtown (3%)	R102AY010SD — Loamy		
		Renwash (2%)	R102AY014SD — Shallow Gravel		
		Castlewood, undrained (1%)	R102AY002SD — Linear Meadow		
EsB	Estelline silt loam, 2 to 6 percent slopes	Estelline (85%)	R102AY010SD — Loamy	37.1	5.7%
		Strayhoss (6%)	R102AY010SD — Loamy		
		Kranzburg (4%)	R102AY010SD — Loamy		
		Goldsmith (3%)	R102AY020SD — Loamy Overflow		
		Badger (1%)	R102AY020SD — Loamy Overflow		
		Renshaw (1%)	R102AY014SD — Shallow Gravel		
Fa	Fairdale loam, channeled	Fairdale, channeled (85%)	R102AY020SD — Loamy Overflow	49.3	7.6%
		Lamoure (13%)	R102AY003SD — Subirrigated		
		Rauville (2%)	R102AY002SD — Linear Meadow		
Fc	Fordtown-Spottswood loams, 0 to 2 percent slopes	Fordtown (55%)	R102AY010SD — Loamy	28.5	4.4%
		Spottswood (30%)	R102AY020SD — Loamy Overflow		
		Divide (9%)	R102AY006SD — Limy Subirrigated		
		Renwash (4%)	R102AY014SD — Shallow Gravel		
		Allivar (1%)	R102AY014SD — Shallow Gravel		
		Marysland, undrained (1%)	R102AY003SD — Subirrigated		
Lk	Lamoure silty clay loam, 0 to 1 percent slopes	Lamoure (75%)	R102AY003SD — Subirrigated	25.3	3.9%
		Lowe (15%)	R102AY003SD — Subirrigated		

Figure 18.16. Sample WSS Soil Data Explorer ecological site assessment information for each Area of Interest soil mapping unit created in Figure 18.15. This information is located under (scroll down) the ecological site map.





**Figure 18.17. Sample WSS Soil Data Explorer ecological site assessment information (Plant Community Transition Diagram) for selected ecological site (e.g., Linear Meadow) for Area of Interest created in Figure 18.15.** This information appears when each ecological site is selected in the left-hand set of drop-down boxes. The diagram on the left shows management impacts on native plant communities.



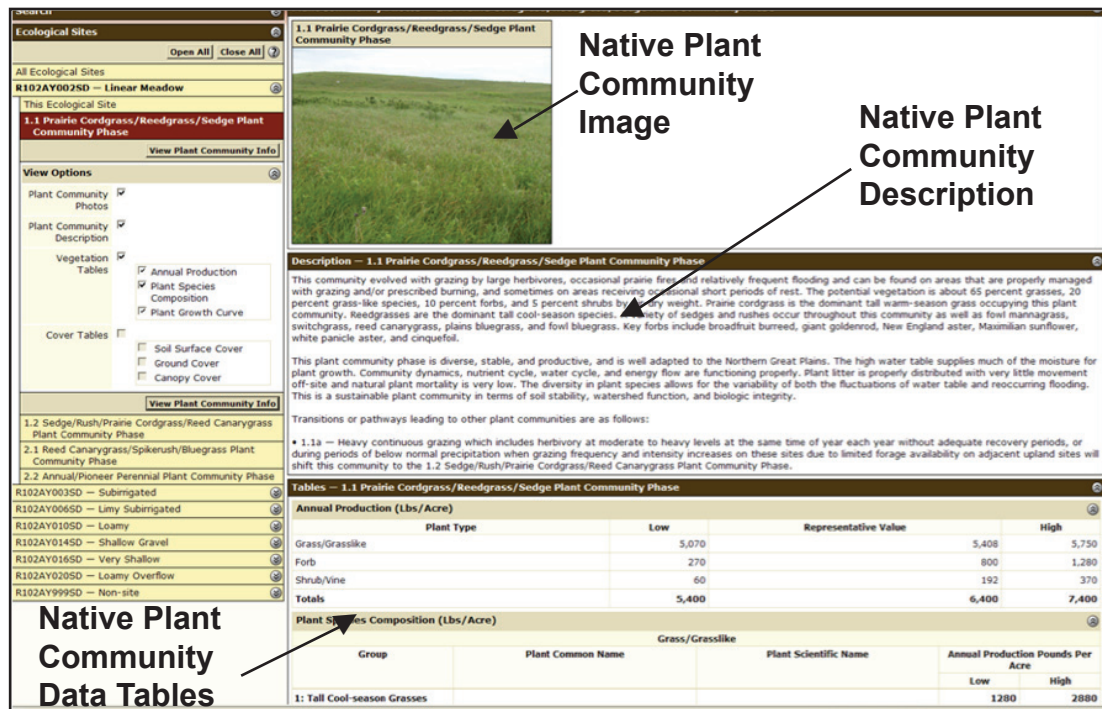


Figure 18.18. Sample WSS Soil Data Explorer ecological site assessment information (individual plant community—Prairie Cordgrass/Reedgrass/Sedge Phase) for selected ecological site (e.g., Linear Meadow) for Area of Interest created in Figure 18.15. This information appears when a specific plant community is selected from a particular ecological site in the drop-down boxes on the left hand side of the window.

In addition to the interpretive maps, you can also download tabular data for your AOI. Tabular data is available when you use the Soil Reports tab in the Soil Data Explorer window (Fig. 18.19, upper right-hand corner). The many possible options for tabular data found in the drop-down menu are located on the left-hand side of the Soil Reports window (Table 18.4 and Fig. 18.20). After the tabular data needed is selected, you can view an explanation of what each table contains by using the View Description tab or View Soil Report tab on the left side of the window.

You can print and/or save the tabular data, description information, and other related materials by using the Printable Version tab or Add to Shopping Cart tab (creates a composite report containing all the information you selected upon completion of your WSS session) in the upper right hand of the Web page window. The selected tables will be printed with interpretive maps and narrative information in the final custom soil survey report.

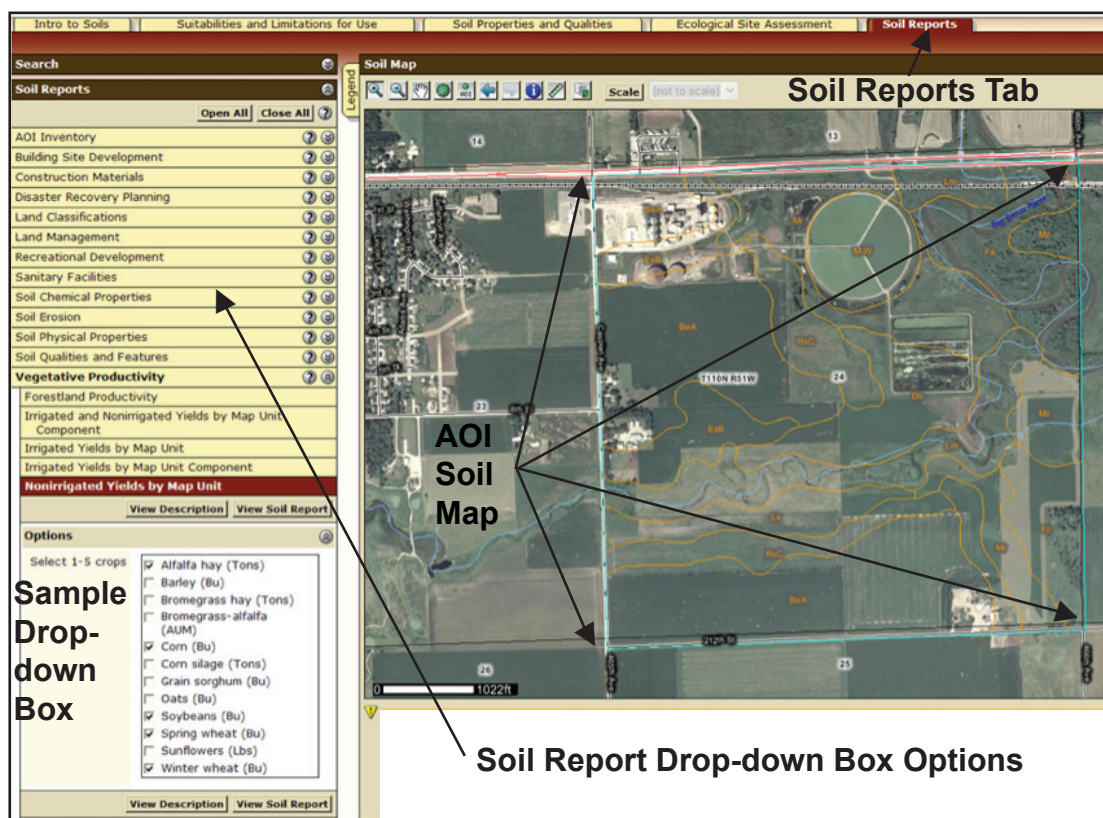


Figure 18.19. Sample WSS Soil Data Explorer window Soil Reports tab with drop-down boxes on the left. If you want all options to be visible in the drop-down area, select the Open All tab. Example – drop-down box for Non-irrigated Yields by map unit is shown. Selected crops for table creation are checked. AOI = Area of Interest.

**Table 18.4. Selected tabular soils data available in the WSS Soil Reports tab folder.**

<b>WSS Soil Report Tabular Data Category*</b>	<b>Category Options*</b>
AOI Inventory	Component Legend Map Unit Description Soil Interpretations
Building Site Development	Dwellings and Small Commercial Buildings Roads/Streets, shallow excavations, lawns and landscaping
Construction Materials	Source for sand and gravel
Land Classifications	Conservation Tree and Shrub Suitability Groups Hydric Soils Land Capability Classifications Prime and Important Farmland Taxonomic Classification of Soils
Land Management	Rangeland Fencing, Resistance to Fugitive Dust Rangeland Site Description and Fire Damage Susceptibility Rangeland Tillage, Compaction Resistance and Soil Restoration
Sanitary Facilities	Sewage Disposal (e.g., septic systems and sewage lagoons)
Soil Chemical Properties	Cation exchange capacity (CEC), pH, lime ( $\text{CaCO}_3$ ), gypsum, salinity, and sodium adsorption ratio (SAR)
Soil Erosion	Attributes for RUSLE2 Equation (estimate soil erosion rates) Windbreaks and environmental plantings
Soil Physical Properties	Engineering soil properties, particle size and coarse fragment content, % sand, % silt, % clay, bulk density, saturated hydraulic conductivity, plant available water holding capacity, % organic matter, erosion factors, linear extensibility (shrink/swell), wind erodibility group and index
Soil Qualities and Features	Restrictive layers (depth and type), frost action, corrosion (steel and concrete)
Vegetative Productivity	Crop yields for major and adapted crops (e.g., alfalfa hay, barley, brome grass hay, brome grass alfalfa hay, corn, corn silage, grain sorghum, oats, soybeans, spring wheat, sunflowers, and winter wheat) Rangeland productivity and plant composition
Waste Management	Agricultural disposal of manure, food processing waste, and sewage sludge Large animal carcass disposal
Water Features	Hydrologic group, surface runoff, water table (depth and duration), flooding (duration and frequency), ponding (duration and frequency)
Water Management	Irrigation (general, sprinkler, surface) Ponds (reservoirs and aquifer-fed excavated ponds) and Embankments (dikes, levees)

*\*Please note that not all WSS Properties and Qualities categories or all options within a category are listed in this table. Some items listed in this table may not be available in all counties and different items of local importance may be present.*

Report — Nonirrigated Yields by Map Unit						
Brookings County, South Dakota						
Map symbol and soil name	Land capability	Alfalfa hay Tons	Corn Bu	Soybeans Bu	Spring wheat Bu	Winter wheat Bu
BeA—Brandt silty clay loam, 0 to 2 percent slopes		3.50	94	34	39	42
Brandt	1					
BeB—Brandt silty clay loam, 2 to 6 percent slopes		3.30	85	31	36	39
Brandt	2e					
Dn—Divide loam, 0 to 2 percent slopes		2.50	73	23	28	30
Divide	3s					
EsB—Estelline silt loam, 2 to 6 percent slopes		2.70	60	22	31	34
Estelline	2e					
Fa—Fairdale loam, channeled		0.40	38	14	6	6
Fairdale, channeled	6w					
Fc—Fordtown-Spottswood loams, 0 to 2 percent slopes		2.90	65	24	28	32
Fordtown	2s					
Spottswood	2s					
Lk—Lamoure silty clay loam, 0 to 1 percent slopes		1.30	76	23	26	27
Lamoure	3w					
Lm—Lamoure-Rauville silty clay loams, channeled		0.30	35	11	6	4
Lamoure, channeled	6w					
Rauville	6w					
M-W—Miscellaneous water areas		—	—	—	—	—
Miscellaneous water	—					
Mr—Marysland loam, 0 to 1 percent slopes		0.40	50	15	13	8
Marysland, undrained	4w					
Mz—Moritz-Lamoure complex, 0 to 2 percent slopes		2.00	78	24	26	27
Moritz	2s					
Lamoure	4w					
Rp—Rauville silty clay loam, ponded		0.00	5	2	1	0
Rauville	8w					
RsC—Renshaw-Sioux complex, 6 to 9 percent slopes		1.40	14	5	11	13
Renshaw	4e					
Sioux	6s					

**Figure 18.20. Sample WSS Soil Data Explorer window Soil Reports table.** Example created based on Figure 18.19. Yields are long-term yields with average management and average weather conditions.

### Step 3. Creation of Custom Soil Survey Report for AOI

After creating all the maps and tables needed and saving them to the Add to Shopping Cart tab, you need to click on the Shopping Cart tab at the top center of the Web page (Fig. 18.21). This option allows you to create your own customized detailed soil survey report. Review the Report Properties and report Table of Contents and make any additions or deletions you may need.

When you are satisfied with the information in the Report Properties and the Table of Contents, select the Check Out tab (upper right-hand corner of window).

For small reports (< 8 MB), a Checkout Options box will appear and you will have the option to receive the report online during the current WSS session or having the report sent by email (receipt within 24 hours) to you. The report (Fig. 18.22) is in pdf format and requires the current version of Adobe Acrobat Reader <http://get.adobe.com/reader/> to open the file.

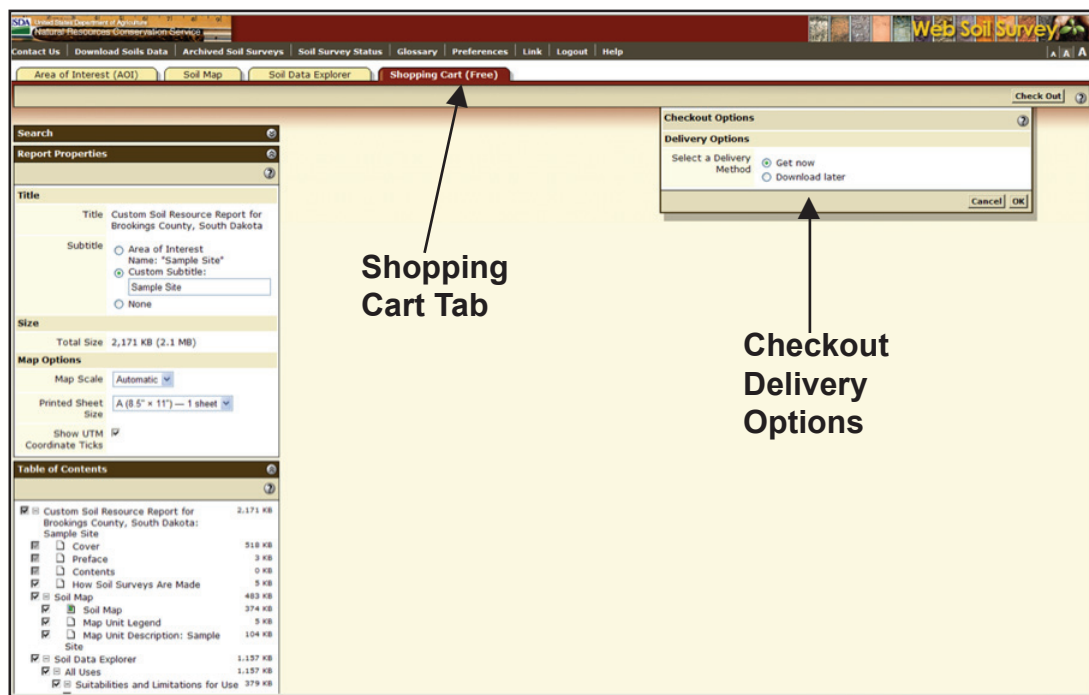


Figure 18.21. Sample WSS Soil Shopping Cart window with the Checkout tab selected (upper right-hand corner).

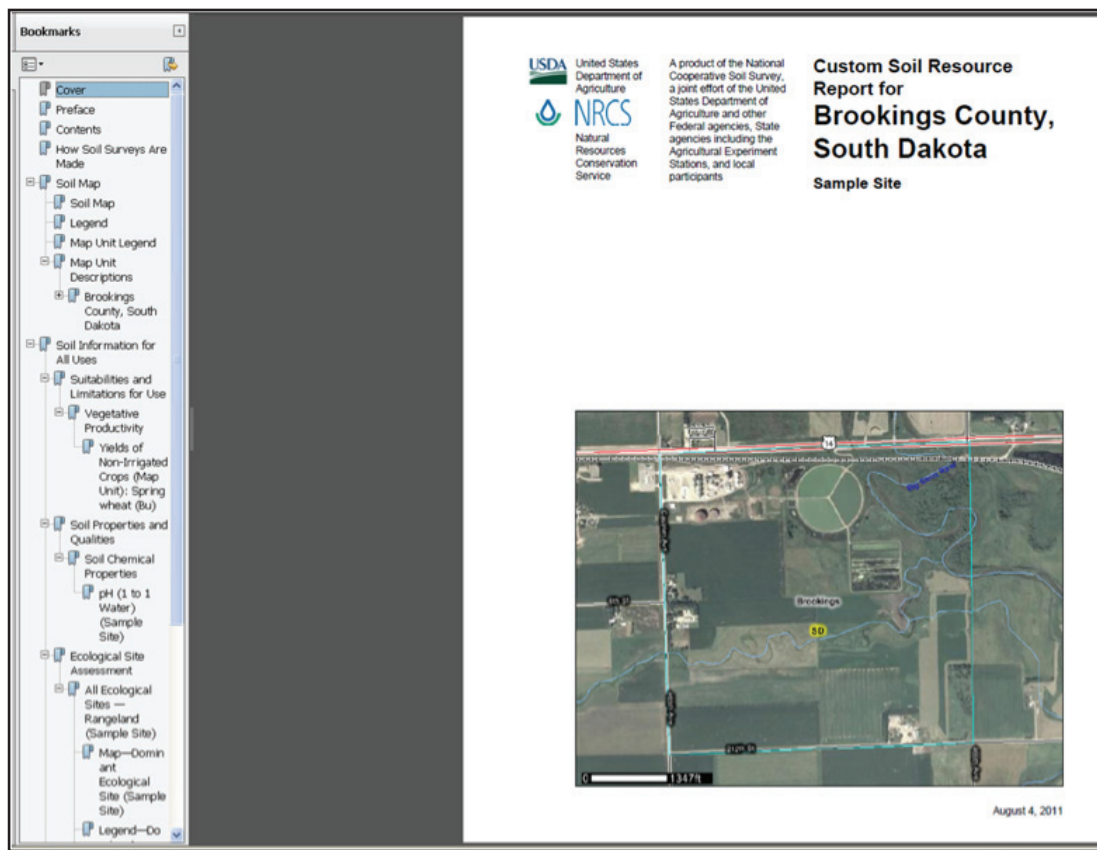


Figure 18.22. Sample WSS Report window. Report can be saved on your computer in pdf format for later use.



### ***Use and limitation of WSS information***

WSS information is useful in understanding how soils differ and will perform under various land management systems. Examination of key soil properties and quality attribute information can aid you in making seeding, fertility, pest management, water/erosion conservation, tillage, and other crop-related management decisions.

Along with yield monitor maps, you can more economically and environmentally manage soil resources using the WSS detailed soil survey data. Producers can integrate WSS data with yield monitor and other collected on-site data (Reitsma and Malo 2011). One key point to remember is that the soil maps in WSS were originally prepared at a scale of 1:20,000 and 1:24,000 for most of South Dakota. As a result, the soil interpretations included inside a soil mapping unit boundary have limitations because of the mapping scale.

The smallest delineation that can be shown on modern soil survey maps in South Dakota is about two acres. Areas smaller than two acres are not shown on the map. Most soil mapping unit descriptions include descriptions of these inclusions to let the user know that these other soils exist in the soil mapping unit.

For intensive management of areas smaller than two acres in size, a more detailed soil map is needed. The soil MUs in WSS allows the user to develop field zones where sound management decisions can be made. With modern GPS, soil survey data, yield monitoring data and scouting reports, it may be possible to increase profitability and reduce the impact of agriculture on the environment.

### ***Conclusion***

This chapter outlines how to use WSS to obtain soil and land attributes for making land-use and management decisions. Samples of output and WSS 2.3 web site use are presented to demonstrate the potential and capabilities of WSS 2.3. In addition, a listing of other websites with valuable soil and natural resource information is given.

There are numerous useful, credible, and user-friendly web sites providing soil and natural resource information. Explore the sites and see the incredible wealth of information available to you online.

## Abbreviations used in this chapter

<b>1:1</b>	– one part soil to one part water
<b>AOI</b>	– area of interest
<b>BLM</b>	– Bureau of Land Management
<b>CaCO<sub>3</sub></b>	– calcium carbonate (lime)
<b>CEC</b>	– cation exchange capacity
<b>cm</b>	– centimeter
<b>CRIS</b>	– Current Research Information System
<b>dS/m</b>	– deciSiemen per meter (measure of electrical conductivity)
<b>EC</b>	– electrical conductivity (soil salinity measurement)
<b>EROS</b>	– Earth Resources Observation Satellite
<b>GIS</b>	– geographic information system
<b>GPS</b>	– global positioning system
<b>HU</b>	– hydrologic unit
<b>K factor</b>	– soil erodibility (soils inherent susceptibility to water erosion)
<b>K<sub>sat</sub></b>	– saturated soil hydraulic conductivity
<b>MLRA</b>	– Major Land Resource Area
<b>MB</b>	– megabyte
<b>mmhos/cm</b>	– millimhos per centimeter (measure of electrical conductivity), 1 mmhos/cm = 1 dS/m
<b>mm</b>	– millimeter
<b>MU</b>	– soil mapping unit
<b>NIFA</b>	– National Institute of Food and Agriculture
<b>NIMSS</b>	– National Information Management and Support System
<b>NOAA</b>	– National Oceanic and Atmospheric Administration
<b>NPS</b>	– National Park Service
<b>NRCS</b>	– Natural resources Conservation Service (formerly the SCS)
<b>PAW</b>	– plant available water holding capacity
<b>Pct, pct</b>	– percent
<b>pdf</b>	– portable document format
<b>pH</b>	– soil reaction
<b>PM</b>	– principal meridian
<b>RUSLE2</b>	– Revised Universal Soil Loss Equation
<b>SAR</b>	– sodium adsorption ratio
<b>SCS</b>	– Soil Conservation Service (now the NRCS)
<b>T value</b>	– tolerable soil loss (maximum amount of soil loss by wind and water and not decrease long-term productivity)
<b>USDA</b>	– United States Department of Agriculture
<b>USDOI</b>	– United States Department of Interior
<b>USFS</b>	– United States Forest Service
<b>USGS</b>	– United States Geological Survey
<b>WSS</b>	– Web Soil Survey



#### **Additional information and references**

California Soil Resource Lab. 2010. SoilWeb: an online soil survey browser. University of California - Davis Soil Resource Laboratory. University of California – Davis.

Available at <http://casoilresource.lawr.ucdavis.edu/drupal/node/902>. Accessed August 9, 2011.

Reitsma, K.D., and D.D. Malo. 2011. Integration of USDA-NRCS web soil survey and site collected data. In Clay, D.E., and J.F. Shanahan (eds). *GIS Applications in Agriculture: Nutrient Management for Energy Efficiency. Volume 2.* CRC Press, Boca Raton, FL.

Malo, D.D. 2008. Online sources of basic soils information. In Logsdon, S., D.E. Clay, D. Moore, and T. Tsegaye (eds). *Soil Science – Step-by-Step Field Analysis.* Soil Science Society of America. Madison, WI.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available at <http://websoilsurvey.nrcs.usda.gov/>. Accessed August 9, 2011.

#### **Acknowledgements**

The author thanks the South Dakota Wheat Commission for their support in the publication of this chapter and book and their continued support of research in the Plant Science Department and the South Dakota Agricultural Experiment Station in the College of Agriculture and Biological Sciences at South Dakota State University.

---

Malo, D.D. 2012. Online web soil survey. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production.* South Dakota State University, SDSU Extension, Brookings, SD.



## CHAPTER NINETEEN

# Managing Saline and Sodic Soils for Wheat Production

*C. Gregg Carlson* ([Gregg.Carlson@sdstate.edu](mailto:Gregg.Carlson@sdstate.edu))

*Ron Gelderman* ([Ronald.Gelderman@sdstate.edu](mailto:Ronald.Gelderman@sdstate.edu))

*David E. Clay* ([David.Clay@sdstate.edu](mailto:David.Clay@sdstate.edu))

*Kurtis D. Reitsma* ([Kurt.Reitsma@sdstate.edu](mailto:Kurt.Reitsma@sdstate.edu))

This chapter discusses wheat production hazards associated with salt-affected soils (Fig. 19.1) and presents guidelines for reducing salt impacts on wheat yield.

### Rules of Thumb for Saline and Sodic Soils

- Saline soils have high concentrations of total salts (including sodium).
- Sodic soils have high concentrations of sodium.
- Production risks and management of saline/sodic problems vary by soil and landform.
- Salt tolerances vary between plant species; wheat yields begin to decline as saturated paste values approach and exceed 6 dS/m.
- Saline problems are best managed with drainage and deep-rooted crops strategically placed in recharge and discharge zones to allow salts to leach from the root zone.
- As the average annual precipitation increases (Iowa has significantly greater precipitation than does South Dakota), the salinity risk usually decreases.
- In a semiarid climate regime, above normal precipitation can raise localized water tables and create salinity problems.
- Methods vary among soil laboratories, giving different results. Some laboratories use a 1:1 water to soil ratio, while others use a saturated paste method.



**Figure 19.1. Salt-affected soil.**  
(Photo courtesy of USDA-NRCS)

Saline soils have high concentrations of soluble cations ('+' charge) and anions ('-' charge) ( $\text{Ca}^{+2}$ ,  $\text{Mg}^{+2}$ ,  $\text{Na}^{+1}$ ,  $\text{K}^{+1}$ ,  $\text{SO}_4^{-2}$ ,  $\text{NO}_3^{-1}$ ,  $\text{Cl}^{-1}$ ), while sodic soils have high sodium concentrations. Saline and sodic conditions impact long-term productivity and soil quality by reducing seed germination, crop growth, and water availability. Sodic soils typically have poor soil water infiltration, tilth, and in severe cases will not support any beneficial plant life. Prevalence of foxtail barley or Kochia can indicate areas of salt accumulation and warrant soil testing to confirm saline and/or sodic conditions.

Saline and sodic soils require similar yet different management techniques. Improved drainage can benefit both but applications of a soluble calcium salt (gypsum,  $\text{CaSO}_4$ ), is usually required to rapidly improve sodic soils. Salt problems can result from a variety of practices including changes in climate and/or management that

impact local hydrologic cycles. In essence, productivity is improved by leaching salts away from the rooting zone.

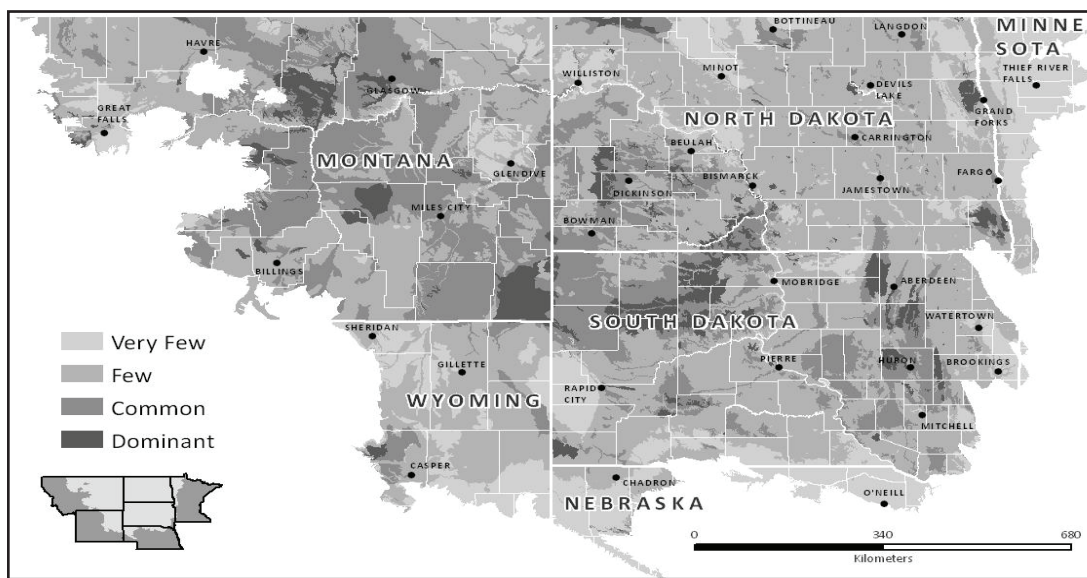
### ***Salt problems, natural or man-made***

Soils with salt problems can result from the weathering of soil and geologic parent materials, management, irrigation, or a combination thereof. Regions in South Dakota with varying degrees of risk for salt problems are shown in Figure 19.2, but are not limited to risk areas shown on the map. At the field scale, the risk salt accumulation is higher in poorly drained areas compared to well-drained soils. The lack of subsoil drainage, periods of above normal precipitation, and/or over-irrigation cause water tables to rise. Salts dissolve in rising water, moving them into the root zone and can be transported to the soil surface. Salts accumulate at the surface as soil water evaporates leaving the salts behind. Reductions in seed germination, crop establishment and vigor, and increases in weeds are likely under these conditions. Saline and sodic conditions are known to be problematic throughout South Dakota.

Irrigation with high sodium or high salinity water is a high-risk practice that can render productive land useless. Over-irrigation can increase salts near the surface in lower areas by raising water tables. Always have irrigation water tested by a reputable laboratory if using a groundwater source. Regardless of the source, proper irrigation scheduling can help to reduce upward movement of salts (Werner 1993).

### ***Impact on plants***

Salt tolerance varies by crop and crop variety; one variety of wheat may be more tolerant than another. Wheat is classified as a moderately tolerant plant (Maas 1984) with a saturated paste EC threshold value of 6.0 dS/m (Fig. 19.3). Maas also indicates that wheat will have a 7.1% yield loss with each 1 dS/m increase above 6 dS/m. Yield losses may be due to reduced plant water availability, seed germination, or combination of both.

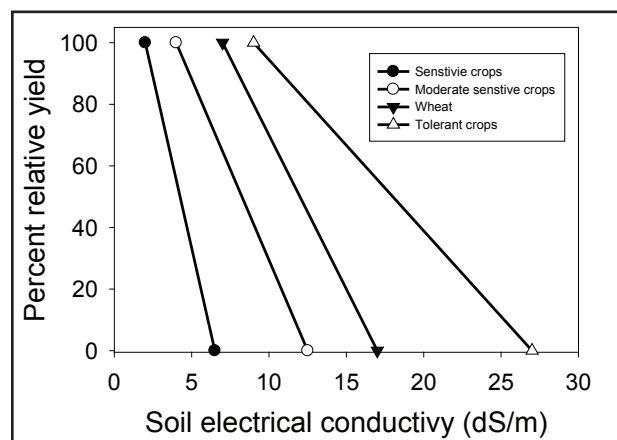


**Figure 19.2. A map of the Northern Great Plains soils with a high risk potential for excessive soil salinity.** Soils with  $EC > 4$  dS/m constitute the high risk areas. (Source: <http://www.soilsci.ndsu.nodak.edu/DeSutter/TomDeSutter.html>)

### Measurement and mapping soil salinity

Automated systems for field measurement of salinity have been developed and provide in-field measurement of “apparent EC” values. Examples of these systems include Geonics EM meters [<http://www.geonics.com/html/em38.html>] and Veris Soil EC [<http://www.veristech.com/products/soilec.aspx>].

The term “apparent EC” is used because results from these instruments are influenced by additional factors beyond salt concentration, including bulk density and soil water content. Apparent EC values are not readily equilibrated to laboratory measurements as it is difficult to define the factor responsible for the EC measurements. However, results from these systems can be used to develop a field map that can be used to define management zones. Areas that have a whitish material appearing on the soil surface should be treated as a separate zone that may require drainage to maximize yields.



**Figure 19.3. Relative crop yield potential as a function of soil salinity.** (Source: D.E. Clay, SDSU)

Typically, laboratory analysis of salts is determined using the saturated paste extraction or a 1:1 soil:water solution. These two methods produce slightly different results (Table 19.1). Research conducted in South Dakota and North Dakota suggests that 1:1 EC dS/m values can be converted to saturated paste EC dS/m values by knowing the soil texture (Table 19.1, Franzen 2003). Because most recommendations are based on saturation paste values, it is important to convert 1:1 ratios to saturation paste values.

EC 1:1	EC Saturated Paste		
	Course Texture Soil	Medium Texture Soil	Fine Texture Soil
0.5	1.4	0.7	0.5
1.0	3.0	2.2	2.0
1.5	4.5	3.7	3.5
2.0	6.0	5.3	5.0
2.5	7.5	6.8	6.5
3.0	9.0	8.3	7.9
3.5	10.5	9.8	9.4
4.0	12.0	11.3	10.9
4.5	13.5	12.8	12.4
5.0	15.0	14.3	13.9
5.5	16.5	15.8	15.3
6.0	18.0	17.3	16.5
6.5	19.5	18.8	18.3
7.0	21.0	20.3	19.8
7.5	22.5	21.8	21.3
8.0	24.0	23.3	22.7

**Table 19.1. The influences of soil texture (coarse, medium, and fine) on the relationship between EC (dS/m) using two approaches (1:1 vs saturation paste).** (Modified from Franzen 2003)

### ***Salinity management: drainage***

High salinity is most often a symptom of a high water table. One option for lowering the water table is to install tile drainage (Chapter 20). A suitable outlet is critical for an effective tile drainage system, but there are many places in South Dakota where suitable outlets are not feasible. In addition, drainage laws require producers to work with local permitting authorities to avoid flooding and other issues.

In 1985, the South Dakota Legislature revised the statutory drainage law giving the authority to manage drainage to county governments. In addition, there is Federal authority administered by the Natural Resource Conservation Service (NRCS).

Pattern tile drains in very coarse-textured soils can be installed on 200 ft centers (using 2011 cost estimates) (~ 220 ft/acre at \$1.50/ft = \$330/acre), while tiling a clay soil may require 10 ft spacing (~4400 ft/acre ~\$6600/acre). Consultation with drainage engineers is recommended when considering tile drainage.

### ***Salinity management: cover and deep-rooted plants***

In some situations, non-drainage solutions can be used. Perennial deep-rooted crops, such as alfalfa, can be used to lower water table and reduce the salinity problem. However, in saline soils alfalfa seeds may not germinate. It may be possible to overcome this problem by:

- Seeding alfalfa in strips several hundred feet wide just above the saline spot.
- Seeding a salt-tolerant crop such as Tall Wheat grass within a salinity pocket.
- Minimizing management practices that physically move salts to the soil surface.

Maintaining plant growth in these areas is critical and weed growth is better than no-growth.

### ***Tillage in saline areas***

In South Dakota, there is a significant opportunity for salt leaching from fall, winter and spring precipitation, assuming the water table is not close to the soil surface. Deep spring tillage can negate the leaching effect by bringing salt to the surface. For this reason, no-till or minimum till farming of salt spots is recommended. Deep ripping has not been found to be a



consistently successful management tool to facilitate deep drainage and lower salt levels of saline areas.

### ***Soil amendments for saline areas***

A saline soil has a high concentration of total salt. Adding additional salts, such as gypsum, will not mitigate the problem; however, gypsum can be effective in reclaiming sodium-affected areas. Drainage and/or increasing plant growth are effective tools to reduce total salinity problems.

### ***Sodium problems***

Sodium (Na) is a salt that requires special attention. High concentrations of sodium on the soil exchange complex can destroy the soil structure. Soils with high Na concentrations will be cloddy with poor infiltration and root growth rates. They may also have dome type structures in the subsoil (Fig. 19.4). Sodium-affected soils can become worse after significant in season or non-growing season precipitation. Leaching of salts from the top several inches of the soil solution may lower total salts, but will leave sodium on the exchange complex. The addition of a calcium-containing material such as gypsum can facilitate movement of sodium off the exchange complex and allow it to move downward with water.

The sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) are two calculations (resulting from a soil test) used to estimate soil sodium problems. Both of these calculations provide estimates of the relative amount of Na contained in the soil. If a Na problem is suspected, a soils specialist should be contacted for advice. Examples of these calculations are available in Clay et al. (2011).

The reclamation of sodium soil is slow because time is required to rebuild the structure.



**Figure 19.4. Dome structure of sodium-affected soil.** (Photo courtesy of USDA-NRCS)

One relatively inexpensive approach to improve the soil structure is to apply low Na-containing manure or to apply crop residues to these areas. The organic matter in these materials can help stabilize and improve soil structure. It must be pointed out that not all manures have low Na concentrations. Manure from animals that have high concentrations of NaCl in their rations may contain high sodium concentrations. For example, 1) distillers grains from ethanol plants may be treated with NaCl; and 2) swine, poultry, and beef have diets that are often supplemented with

NaCl. Many animals have diets supplemented with NaCl because the plant materials do not provide enough Cl or Na to meet the animals' nutritional requirement.

A second approach is to replace the Na on the soil exchange site with a calcium source such as gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) or lower the pH of the soil with elemental sulfur. As a rule of thumb, South Dakota soils should not exceed SAR values (~ESP) values of 8. For a typical South Dakota soil with a CEC of 25 and a SAR value of 12, a one-ton application of gypsum would be needed to lower the SAR value to 8, in the top 6 inches of soil. To lower the content of the top 6 inches of this same soil from a SAR of 12 to 4 will require about 2 ton/acre of gypsum.

Elemental sulfur is an additional option. Sulfur oxidizes to sulfuric acid which reacts to form gypsum if calcium carbonate is present. To displace the Na on the soil exchange site, good quality water must be added to leach the Na beyond the root zone.

### *Summary*

In managing saline and sodic soils, care must be used to prevent further degradation. Some approaches to prevent further degradation are:

1. Collect soil and irrigation water samples to identify the scope and magnitude of the problem.
2. Plant salt-tolerant plants.
3. Eliminate sources of salt or balance salt additions with salt losses.
4. Apply gypsum to sodic soils, if needed.
5. Apply crop residues or animal manure low in Na to improve water infiltration.
6. Install tile drainage.

In soils with high water tables, salts can concentrate near the soil surface. In these areas, water and the salts dissolved in the water rise through capillary movement from the water table to the surface. As the water evaporates, it is replaced by more salt-containing water from the water table. Approaches for reducing capillary movement of water and salts to the surface include:

1. Install tile drainage.
2. Properly manage irrigation systems.
3. Adopt practices that maximize transpiration and minimize evaporation.
4. Plant full season deep-rooted crops or shelterbelts in these and in the recharge areas.
5. Eliminate fallow.

For sodic soils, extreme care must be used. High sodium has the added problem in that it can greatly reduce water infiltration. If a sodium problem is suspected, an agronomist should be contacted for assistance. Ultimately a soil sample should be collected and the sodium adsorption ratio (SAR) calculated (Clay et al. 2011).

If the SAR is greater than 8, a long-term plan that minimizes further degradation should be adopted. The plan may include providing tile drainage, adding low Na manure or gypsum, or lowering the pH (if the soil pH is high) with elemental S. If gypsum is present at deeper soil depths, tillage may help. If drainage and soil amendments are not possible, consider placing the field into pasture and planting it with salt-tolerant grasses.



#### Additional information and references

Abrol, I.P., J.S.P. Yadav, and F.I. Massoud. 1988. Salt-affected soil and their management. *FAO Soil Bulletin* 39. Available at <http://www.fao.org/docrep/x5871e/x5871e00.htm>

Clay, D.E., S.A. Clay, C.G. Carlson, and S. Murrell. 2010. *Mathematics and Calculations for Agronomists and Soil Scientists*. International Plant Nutrition Institute. Available at <http://ppi-store.stores.yahoo.net/maandcaforag.html>

Franzen, D. 2003. *Managing saline soils in North Dakota*. SF-1087. North Dakota State University Extension Service, Fargo, ND. Available at <http://www.ext.nodak.edu/extpubs/plantsci/soilfert/sf1087-1.htm>

Maas, E.V. 1984. Salt tolerance of plants. In B.R. Christie (ed.) *Handbook of Plant Science in Agriculture*. CRC Press, Boca Raton, FL.

Reitsma, K.D., T.E. Schumacher, and D.E. Clay. 2011. Soil quality. In D.L. Deneke (ed.) *Alternative Practices for Agronomic Nutrient and Pest Management for South Dakota*. South Dakota State University, iGrow, and SDSU Extension, Brookings, SD.

USDA. 1954. *Diagnosis and improvement of saline and alkali soils*. Agric. Handbook. No. 60. United States Salinity Laboratory, Riverside, CA.

Werner, H. 1993. *Checkbook irrigation scheduling*. EC987. SDSU Extension, Brookings, SD. Available at <http://www.sdstate.edu/sdces/store/Publications/search.cfm>

#### Acknowledgements

Support for this chapter was provided by South Dakota State University, South Dakota Corn Utilization Council, USDA-NIFA, South Dakota 2010 research program, South Dakota Wheat Commission, and the South Dakota Soybean Board.

---

Carlson, C.G., R. Gelderman, D.E. Clay, and K.D. Reitsma. 2012. Managing saline and sodic soils for wheat production. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.





## CHAPTER TWENTY

# Managing High Water Tables and Saline Seeps in Wheat Production

Chris Hay ([Chris.Hay@sdstate.edu](mailto:Chris.Hay@sdstate.edu))

Todd Trooien ([Todd.Trooien@sdstate.edu](mailto:Todd.Trooien@sdstate.edu))

Too much water and high salt concentrations are harmful for crops. This chapter will address the management of high water tables and the basic reclamation principles for saline seeps.

### *Lowering high water tables with subsurface drainage*

Subsurface (tile) drainage is used to remove excess soil water using drainage pipes or tiles installed below the soil surface (Fig. 20.1). Since the 1970s, perforated polyethylene tubing



has become the most popular material for drainage pipes. Historically, however, cylindrical clay or concrete sections, or “tiles,” were used, so the customary terms “tiling” and “tile drainage” are still used to describe subsurface drainage. Drains are typically installed just below the root zone at depths of 2.5 to 4 ft. The outlet for tile lines is generally streams or open ditches.

**Figure 20.1. Water flowing from the outlet of a subsurface drain.** (Photo by Lynn Betts, USDA Natural Resources Conservation Service)

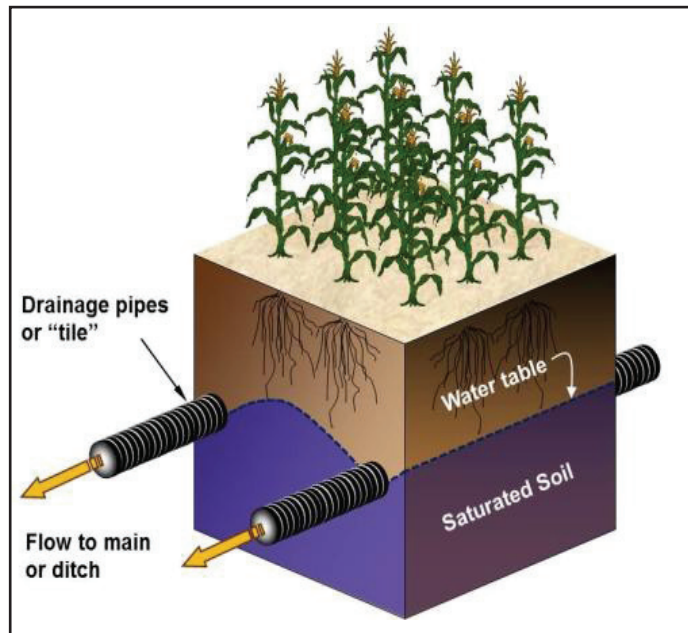
Subsurface drainage is used to enable more timely planting, harvesting, and other field operations and to increase crop yields. Many South Dakota soils have poor natural drainage, and without artificial drainage they would remain waterlogged from excess precipitation for extended periods.

Approximately 25% of the farmable acres in the U.S. have some form of artificial drainage. By removing excess water from the root zone (Fig. 20.2), salts are flushed from the root zone, and the risk of soil compaction from field operations is reduced. Since soils with subsurface drainage will dry out and warm up faster in the spring than undrained soils, subsurface drainage can enhance the ability to implement no-till and minimum tillage.

Along with improved yields, subsurface drainage tends to reduce surface runoff and peak flows by encouraging increased infiltration of water into the soil. Zucker and Brown (1998)

reported that subsurface drainage reduces surface runoff by 29 to 65%, peak flows are reduced by 15 to 30%, and total outflows (surface runoff plus subsurface drainage) are similar. Other studies have shown modest increases (5 to 10%) in total outflows from the addition of subsurface drainage.

The impacts of subsurface drainage on water quality can be both positive and negative. Because subsurface drainage reduces surface runoff, sediment and nutrient losses from surface runoff are also reduced. Sediment loss reductions range from 16 to 65%, and losses of phosphorous may be reduced up to 45%



**Figure 20.2. Subsurface drainage removes excess water from the root zone via pipes or "tile" buried beneath the soil surface.** (Illustration courtesy of Gary Sands, University of Minnesota)

(Zucker and Brown 1998). However, subsurface drainage can increase nitrate transport. Nitrate losses from subsurface drainage vary widely, but concentrations of nitrate in drainage water frequently exceed the drinking water standard.

Conservation drainage constitutes a set of established and new designs and practices designed to maintain the benefits of drainage, while reducing negative environmental impacts. This is an active area of research, and a number of conservation drainage demonstration projects are being implemented in the Midwest. These practices include:

1. Controlled drainage to reduce nitrate loss from fields.
2. Woodchip bioreactors to remove nitrates from drainage water.
3. Constructed wetlands.
4. Shallow drainage.
5. Two-stage ditches.

South Dakota drainage law delegates regulatory authority of drainage to the county level. So, an important first step in planning any drainage project is to consult with the county drainage board (in many counties, the board of county commissioners is also the drainage board). Other states have different governing authorities for regulating drainage activities. In addition to county regulations, the Swampbuster provisions introduced in the 1985 Food Security Act (Farm Bill) discourage the drainage of wetlands for agricultural use. Therefore, local USDA Farm Service Agency and Natural Resources Conservation Service offices must be consulted about drainage plans. Draining wetlands can result in the unintended loss of farm program benefits.

When preparing a drainage plan, it is useful to gather background information from county soil surveys, topographic maps, aerial photos, climate data, local water management authorities, and drainage guides from neighboring states (e.g., Minnesota and Iowa). Obtaining more detailed data (topographic surveys and soils characterizations) for areas to be drained is also a good idea.

### ***Economics***

A primary goal of subsurface drainage is increased profit for the producer. Because installing a subsurface drainage system involves a significant investment, an economic feasibility study should be conducted. Factors that should be considered are expected yield response, impact on equipment and material costs, and costs of the drainage system over the life of the drainage system. Although the actual lifetime of a well-designed drainage system may be 50 to 100 years, the economic lifetime of the drainage system is often assumed to be 20 to 30 years.

Estimating values to use in the economic analysis, particularly yield response, is difficult. Comparisons of combine yield monitor data from poorly drained and adequately drained areas of a field may give some indications of potential yield response when drainage improvements are made. Other potential sources of information include neighboring producers who have installed drainage systems and drainage contractors. As an example of yield increases following drainage, data based on 20 years of yield records from Ontario showed yield increases of 17 bushels per acre (38% increase) for winter wheat and 11 bushels per acre (33% increase) for spring wheat (Irwin 1998). Additional information is available in Hofstrand (2010) and online calculators.

Prinsco at <http://www.prinsco.com/article.cfm?ID=96>

Advanced Drainage Systems at <http://www.ads-pipe.com/en/documentlisting.asp?documentTypeID=40>

### ***Drainage outlet***

Subsurface drainage systems will only perform as well as the outlet, so good drainage design should begin by ensuring there is a suitable outlet. Where drains outlet into a natural or manmade open channel, depth and capacity are important considerations. The channel should be deep enough so that the bottom of the drain outlet is at least 1 ft above the normal low-water level in the waterway when the drains are installed at the desired depth. Proper maintenance is needed to prevent drainage ditches from becoming clogged by sediment and/or by vegetation growth. Consequently, erosion and weed control are essential to ensure that these systems continue to function effectively.

Any existing drainage outlet should be checked to see if it can handle additional water, and if it is deep enough to allow the planned additional field drains to be placed at the desired depth. Pumped outlets may be considered where there is an otherwise adequate outlet that is not deep enough to allow for gravity drainage. The outlet should be protected from rodents or other small animals, washout, and erosion.

In addition to the physical requirements for an outlet described above, the outlet must also meet all legal and regulatory requirements for drainage outlets. In general, the drainage should occur through a natural or established watercourse and should not substantially alter the flow such that it causes unreasonable harm downstream. In many cases, downstream notification or approval may be required as part of the regulatory process. Regardless, drainage problems are often not limited to a single property, so working with neighbors to address drainage problems can result in more effective solutions and less potential for disputes.

### ***Surface intakes***

Surface intakes can be used to remove ponded water from closed depressions or potholes through the subsurface drainage system. If surface intakes are added to a subsurface drainage system, the system should be sized to accommodate the concentrated flow entering from the surface. Surface intakes can be a source of weakness in the drainage system, so offsetting them on a short lateral will help protect the main.

By providing a direct connection to water at the surface, these intakes can serve as a shortcut for sediment, nutrients, or other pollutants to travel to downstream surface water bodies. Open intakes that are flush with the surface, in particular, should be avoided for this reason. Slotted or perforated risers allow for some settling of sediments before water enters the intake. A permanent grass buffer should be provided around the riser to trap sediment and other pollutants before they reach the intake. Rock or “blind” inlets are another option that eliminates the need for a riser by filtering out sediment before it enters the drain.

### ***Drainage coefficient***

The drainage system should be designed to remove excess water from the active root zone to prevent crop damage within 24 to 48 hours of excess precipitation. The rate at which the drainage system can remove water from the soil is commonly called the drainage coefficient, and it is a measure of the system capacity. The drainage coefficient is typically expressed as the depth of water removed in a 24-hour period (inch/day). Because drain spacing and sizing will be determined by the drainage coefficient, the choice of a drainage coefficient is an economic as well as an agronomic decision.

If surface inlets will be used to directly drain water from the surface through the drain pipes, a larger drainage coefficient should be used to account for the additional water coming from the surface. Typical drainage coefficients for humid regions are shown in Table 20.1. Choice of an appropriate drainage coefficient should be made based on local conditions, experience, and judgment. Because South Dakota is in a transition zone from humid to semiarid regions, a smaller drainage coefficient of ¼ inch per day may sometimes be an appropriate choice.



Table 20.1. Typical drainage coefficients for humid areas. (ASAE EP480 standard)			
	No Surface Inlets (in./day)	Blind Surface Inlets (in./day)	Open Surface Inlets (in./day)
<i>Mineral Soils</i>			
Field crops	$\frac{3}{8} - \frac{1}{2}$	$\frac{1}{2} - \frac{3}{4}$	$\frac{1}{2} - 1$
High value crops	$\frac{1}{2} - \frac{3}{4}$	$\frac{3}{4} - 1$	$1 - 1\frac{1}{2}$
<i>Organic Soils</i>			
Field crops	$\frac{1}{2} - \frac{3}{4}$	$\frac{3}{4} - 1$	$1 - 1\frac{1}{2}$
High value crops	$\frac{3}{4} - 1\frac{1}{2}$	$1\frac{1}{2} - 2$	$2 - 4$

### Drain depth and spacing

The depth and spacing of parallel drains necessary to achieve a certain drainage coefficient are determined in large part by the hydraulic conductivity (permeability) of the soil and the depth to a low permeability barrier. For single targeted drains, the hydraulic conductivity and depth to the barrier will determine the effective distance from the drain that will be adequately drained given the depth of the drain. Depth and spacing should be considered simultaneously when trying to achieve a desired drainage coefficient.

As shown in Figure 20.2, the water table will be highest midway between two parallel drains and lowest at the drains themselves. The depth and spacing are chosen to maintain a minimum depth to the water table midway between the drains. The height that the water table will reach above the drains will be less for drains spaced more closely together. Therefore, deeper drains can be spaced further apart, whereas shallower drains need to be closer together to achieve the same drainage coefficient. Table 20.2 lists general drain depth and spacing recommendations based on soil type. More specific depth and spacing recommendations should be based on measured soil properties or drainage experience with similar soils and conditions.

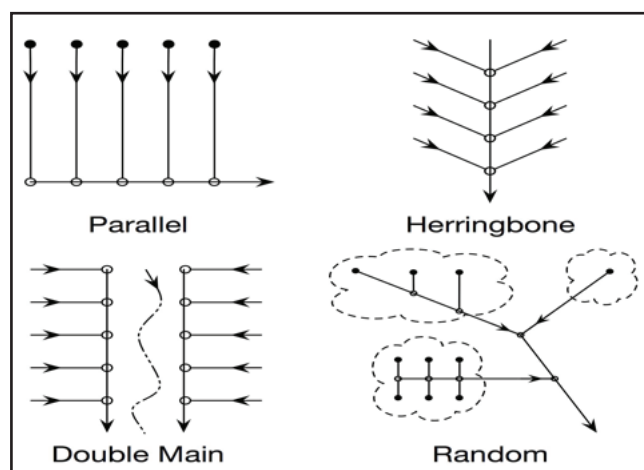
Table 20.2. Typical drain spacing and depths for parallel drains for various soils. (Wright and Sands, 2001)					
		Drain Spacing (ft)			
Soil Type	Permeability	Fair Drainage ( $\frac{1}{4}$ in./day)	Good Drainage ( $\frac{3}{8}$ in./day)	Excellent Drainage ( $\frac{1}{2}$ in./day)	Drain Depth(ft)
Clay loam	Very low	70	50	35	3.0–3.5
Silty clay loam	Low	95	65	45	3.3–3.8
Silt loam	Moderately low	130	90	60	3.5–4.0
Loam	Moderate	200	140	95	3.8–4.3
Sandy loam	Moderately high	300	210	150	4.0–4.5

Drains are typically placed 3 to 4 ft deep. If possible, drains should be placed above shallow, low permeability layers. The minimum depths to avoid damage from heavy equipment are 2 ft for laterals (3 to 6 in. diameter pipes) and 2.5 ft for mains (8 in. or greater diameter pipes). Ideally drainage systems would have uniform depth, but field topography and layout decisions will determine actual drain depths.

### ***System layout***

The layout of the drainage system, along with the design decisions made above, will determine the uniformity of drainage for the field or area. Drainage system layout is chosen to best match field topography and outlet location. Topography will dictate what layout options are practical. There are several layout options available for drainage systems (Figure 20.3). Parallel drainage systems are used to drain large areas or entire fields of regular shape and uniform soils. Herringbone systems are typically used in relatively narrow depressions such as those along shallow drainageways.

Double main systems are used where a larger or deeper drainageway divides the field. Targeted drainage systems are used where there are isolated wet areas that require drainage. Mains are run through natural low areas toward the outlet, and laterals may be added to provide drainage for larger wet areas. For any layout pattern, a general guideline to follow when laying out the system is to align laterals along the field contours to the extent possible. This allows the laterals to act as interceptors of water as it moves down the slope. Collectors or mains are then placed on steeper grades or in swales to allow for a more uniform lateral gradeline.



**Figure 20.3.** Typical drainage system layout options for lowering a water table.

### ***Drain grades and envelopes***

Drainage systems should be designed such that both minimum and maximum grade recommendations are followed. This is to ensure that flow velocities are within an acceptable range. The grade should be sufficient to prevent sediments from accumulating in the drains and shallow enough to prevent excessive pressure that could result in erosion of soil around the drain. Drains in stable soils (clay content greater than 25 to 30%) can be placed on shallower grades. Soils lower in clay with more fine sands and silt require steeper grades. Table 20.3 lists the minimum recommended grades for various pipe sizes depending on whether fine sands and silts are likely to be a problem. In addition to minimum grades, the use of drain envelopes should be considered for soils high in fine sands and silts, particularly if shallower grades must be used. Materials used for drain envelopes include gravel, synthetic fiber membranes, and pre-wrapped geotextiles (or “socks”).

To prevent problems with excessive pressures and velocities, mains should not be placed on grades greater than 2% where practical. When steeper grades must be used, additional precautions should be taken, which may include the use of pressure relief wells. Large changes in grade, particularly steep-to-flat, should be avoided to prevent the risk of blowouts. Reversals in grade must always be avoided.

<b>Table 20.3. Minimum recommended grades (% or ft/100 ft) for drainage pipes</b> where CPE is corrugated polyethylene plastic pipe and smooth refers to smooth wall plastic pipe or concrete or clay tile. (ASAE EP480 standard)				
<b>Inside diameter of drain (in.)</b>	<b>Drains not subjected to fine sand or silt (min. velocity of 0.5 ft/s)</b>		<b>Drains subjected to fine sand or silt (min. velocity of 1.4 ft/s)</b>	
	<b>CPE</b>	<b>Smooth</b>	<b>CPE</b>	<b>Smooth</b>
3	0.10	0.08	0.81	0.60
4	0.07	0.05	0.55	0.41
5	0.05	0.04	0.41	0.30
6	0.04	0.03	0.32	0.24

### ***Drain pipe sizing***

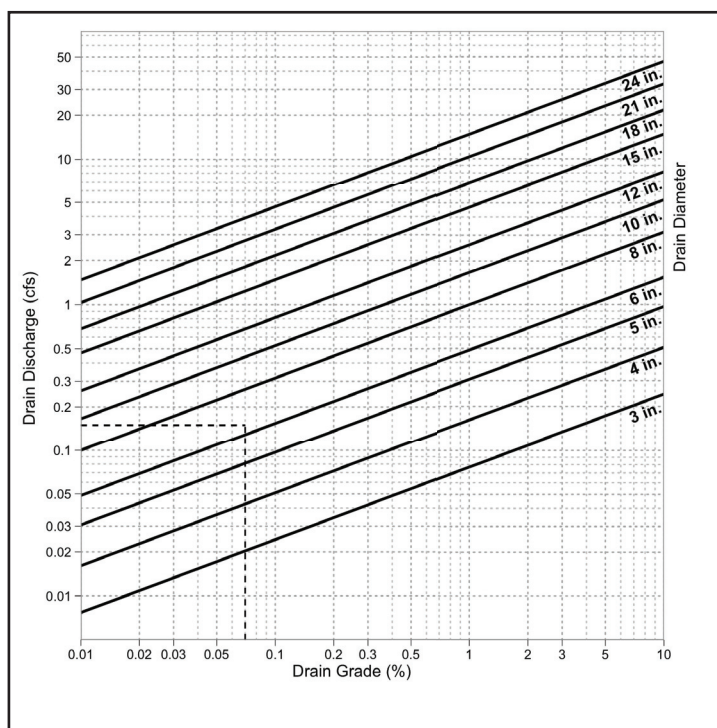
The recommended size of drainage pipe depends on the area to be drained, the chosen drainage coefficient, the grade on which the pipe is laid, and the pipe materials (corrugated plastic or smooth-wall, plastic or concrete, pipe). To determine the required flow that the pipe must handle, the following equation can be used:

$$Q(\text{cfs}) = \frac{\text{Area (acres)} \times \text{DC (inches/day)}}{23.8}$$

Where Q is the required flow rate (capacity) in cubic feet per second (cfs), the area to be drained is in acres, and the drainage coefficient (DC) is in inches per day. For example, the flow capacity needed to drain 40 acres with a 3/8 in. drainage coefficient is: 40 acres x 0.375 in./day ÷ 23.8 = 0.63 cfs.

To size the outlet, the total area to be drained by that outlet should be used. For sizing individual laterals, only the area drained by the lateral is used. If future expansion of the drainage system is likely, the outlet should be sized to accommodate that expansion. Once the required flow is calculated, the pipe size (diameter) necessary to carry that flow can be determined based on the grade and the pipe material. Figure 20.4 can be used to determine necessary pipe size for corrugated plastic pipe. Other sources for determining necessary pipe size include:

- Manufacturer's literature.
- Slide calculators from drain pipe manufacturers (e.g., Prinsco, Hancor, and ADS).
- Web-based calculators.
  - [http://www.extension.umn.edu/AgDrainage/online\\_calculator.html](http://www.extension.umn.edu/AgDrainage/online_calculator.html)
  - <http://www.prinsco.com/article.cfm?ID=98>
  - <http://www.ads-pipe.com/en/documentlisting.asp?documentTypeID=40>
- Drainage contractors and engineers.



**Figure 20.4. Chart for determining the required size of corrugated plastic pipe based on the pipe grade (in percent) and the design discharge (in cubic feet per second).**

The solid black lines represent the discharge of a pipe of the size indicated that is flowing full, based on the drain grade. The space between the solid black lines represents the range of pipe capacity for the pipe size indicated between the solid lines.

For drain grade and discharge combinations that do not fall directly on one of the solid lines, the next larger commercial pipe size would be chosen. For example, the required drain size for a drain grade of 0.07% and a design discharge of 0.15 cfs would be an 8-inch pipe (dashed black lines).

(Adapted from ASAE EP480 standard)

### ***Installation considerations***

In addition to a good design, the quality of installation is also important in determining how well a drainage system will perform. Once a drainage system is installed, correcting any problems is difficult and expensive. It is, therefore, important to make sure that drainage installation is done on grade and is of high quality. An experienced and reliable contractor can be an asset in achieving a quality installation. The equipment used for installation can also influence the quality of installation. Tractor mounted and pull-type plows can perform well, but good grade control can be more difficult to manage.

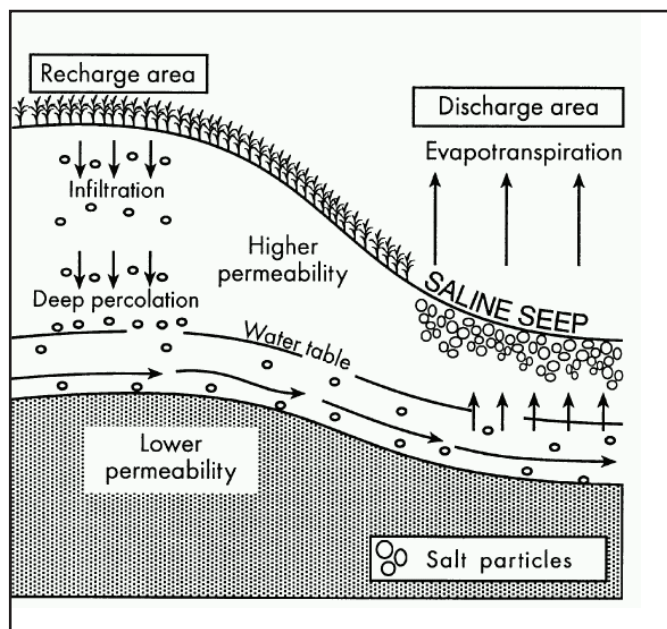
Shallow or flat grades, in particular, have a smaller margin for error, so accurate grade control is especially important under those conditions. As-built plans showing the dimensions and locations of all drains should be prepared following or during (such as those created by GPS systems) installation and kept as part of the farm records. These plans will facilitate any future expansion or required maintenance of the drainage system. Problems to watch for following installation include wet spots in the field where drains were installed, sedimentation at the outlet, blockages of the outlet, and erosion damage around the outlet.

### ***Saline seeps***

Another problem caused by excess water is the saline seep. A saline seep is the discharge location for shallow groundwater. The water also carries any soluble salts or nutrients that it encountered in the soil. Over time, the seep area becomes too wet and too saline, either reducing crop performance or preventing crop growth. Additional information on the management of saline soils is available in Chapter 19.

Saline seeps start when water from rain or snowmelt enters the soil in a recharge area. This recharge area is often located some distance from the seep and must be higher in the landscape (Figure 20.5). If the water is not used by a crop in the recharge area, it eventually drains downward and leaves the root zone. If the water draining downward reaches a layer of

high lateral permeability, then the water can move laterally in that layer. If the topography is such that the zone of high lateral permeability intersects or approaches the soil surface, the water will re-emerge on the soil surface as a saline seep.



**Figure 20.5. A diagram showing saline seep hydrology.** Water moves from the recharge area, through the zone of lateral permeability, and back to the soil surface in the discharge area (which is the seep).

As it moves through the soil, the water dissolves and carries soluble salts and nutrients (Mankin and Koelliker, 2000).

Reprinted with permission of the American Society of Agricultural and Biological Engineers, St. Joseph, MI.

As the water moves through the soil, it dissolves salts and soluble nutrients. If and when the water reappears on the soil surface, those salts and nutrients arrive with the water and are deposited on the soil surface. Magnesium and sodium salts are often found in seep areas. Seep areas with high sodium salts must be managed carefully (Chapter 19). Saline seeps can also have high nitrate-nitrogen concentrations.

The excess water in the seep causes can prevent access by equipment and reduce the plant root functioning. The salts interfere with water uptake and reduce or even prevent plant growth. Sodium salts can cause problems with the soil itself, reducing infiltration rates. Nitrate-nitrogen is a vital crop nutrient and can be used by growing plants. High nitrate concentrations in these areas generally are not a concern unless it gains entry to a drinking water supply and causes nitrate-nitrogen concentrations in excess of the maximum contaminant level of 10 mg/L (ppm).

Control of a saline seep starts in the recharge area. The precipitation that falls on the recharge area must be prevented from leaving the root zone. That is, the crop (vegetation) water use must be increased in the recharge area so water is used up before it can drain out the bottom of the root zone. Crop water use can be increased by increasing the cropping intensity. Some strategies for increasing the cropping intensity include annual cropping instead of fallow.

Another strategy is planting alfalfa in the recharge area. This is a good option because alfalfa has a high water use each growing season, and alfalfa has deep roots, using water and nutrients deeper in the soil profile, when compared to small grain crops. Planting alfalfa may not be required for the entire recharge area. In the central Great Plains, planting one-third of the recharge area to alfalfa has been shown to reduce water movement to a seep by one-half or more.

Any crop rotation that decreases the amount of time the recharge area is fallow will help reduce or eliminate the active mechanism supporting a saline seep. When the increased cropping intensity in the recharge area has effectively controlled the water, the seep area will respond in one or two years, depending on the weather. More rainfall will cause greater leaching in the seep, reducing the time until the area is fit again for crop production.

When the water is effectively controlled in the recharge area, some management practices in the seep area can hasten reclamation. Straw mulch has been shown to be effective at increasing the rate of salt removal from the seep area. Other practices that conserve soil water in the seep area will increase the rate of salt removal by increasing the water drainage and leaching.

Interceptor drains have been tried in reclaiming saline seeps. However, the intercepted saline water poses a disposal problem. In addition, the interceptor drainage strategies have been shown to be less than successful at reducing water and salt flow to the seep.

Irrigation has been used to impose downward water movement in the seep itself, moving water and salts downward and out of the root zone. This can be effective in moving salts out of the root zone, especially if accompanied by artificial drainage within the seep area. However, the drain water disposal issue is still a problem, and resalinization can occur during the non-growing (and non-irrigating) season. In summary, saline seeps are caused by excess water coming from a location higher in the landscape. Reduction or reclamation of the saline seep starts with intensified cropping in the recharge area.

#### Additional information and references

Black, A. L., P. L. Brown, A. D. Halvorson, and F. H. Siddoway. 1981. Dryland cropping strategies for efficient water-use to control saline seeps in the northern Great Plains, USA. *Agric. Water Manage.* 4:295-31.

Blann, K., J. L. Anderson, G. Sands, and B. Vondracek. 2009. Effects of agricultural drainage on aquatic ecosystems: A review. *Crit. Rev. Env. Sci. Tec.* 39(11):909-1001.

Busman, L. and G. Sands. 2002. Issues and answers. BU-07740-S. University of Minnesota Extension. Available at <http://www.extension.umn.edu/distribution/cropsystems/DC7740.html>

Dimnes, D. L., D. L. Karlen, D. B. Jaynes, T. C. Kaspar, J. L. Hatfield, T. S. Colvin, and C. A. Cambardella. 2002. Nitrogen management strategies to reduce nitrate leaching in tile drained Midwestern soils. *Agron. J.* 94(1):53-171.

Doering, E. J. and F. M. Sandoval. 1976. Hydrology of saline seeps in the Northern Great Plains. *Trans. ASAE* 19(5):856-861, 865.

Frankenberger, J., E. Klavivko, G. Sands, D. Jaynes, N. Fausey, M. Helmers, R. Cooke, J. Strock, K. Nelson, and L. Brown. 2006. Drainage water management for the Midwest: Questions and answers about drainage water management for the Midwest. Purdue Extension Publication WQ-44. Available at <http://www.ces.purdue.edu/extmedia/WQ/WQ-44.pdf>

Franzen, D. 2007. Managing saline soils in North Dakota. SF-1087 (revised). North Dakota State University Extension. North Dakota State University, Fargo, ND. Available at <http://www.ag.ndsu.edu/pubs/plantsci/soilfert/sf1087-1.htm>

Halvorson, A. D. 1984. Saline-seep reclamation in the Northern Great Plains. *Trans. ASAE* 27(30):773-778.

Helmers, M. 2008. Iowa drainage guide. SR 0013. Iowa State University Extension. Available at: <https://www.extension.iastate.edu/store/ItemDetail.aspx?ProductID=6064&SeriesCode=&CategoryID=&Keyword=SR%2013>

Hofstrand, D. 2010. Understanding the economics of tile drainage. C2-90. Iowa State University Extension. Available at <http://www.extension.iastate.edu/agdm/wholefarm/html/c2-90.html>

Irwin, R. W. 1999. 20 year record of drainage benefit. Factsheet No. 9. Land Improvement Contractors of Ontario. Available at <http://www.drainage.org/factsheets/fs9.htm>



Mankin, K R and J K Koelliker. 2000. A hydrologic balance approach to saline seep remediation design. *App. Eng. Agric.* 16(2):129-133.

Nyvall, J. and T. Van der Gulik. 1984. Subsurface drainage system installation: What to expect from your drainage contractor. 541.000-1. British Columbia Ministry of Agriculture and Food. Available at <http://www.agf.gov.bc.ca/resmgmt/publist/500Series/541000-1.pdf>

Sands, G. R. 2008. The drainage outlet. University of Minnesota Extension. Available at <http://www.extension.umn.edu/AgDrainage/>

Sands, G. R., I. Song, L. M. Busman, and B. Hansen. 2008. The effects of subsurface drainage depth and intensity on nitrate load in a cold climate. *Trans. ASABE* 51(3):937-946.

Wright, J. and G. Sands. 2001. Planning an agricultural subsurface drainage system. BU-07685-S. University of Minnesota Extension. Available at <http://www.extension.umn.edu/distribution/cropsystems/DC7685.html>

Zucker, L. A. and L. C. Brown (eds.). 1998. Agricultural drainage: Water quality impacts and subsurface drainage studies in the Midwest. Bulletin 871-98. Ohio State University Extension. Available at <http://ohioline.osu.edu/b871/index.html>

#### **Acknowledgements**

Thanks to Gary Sands, University of Minnesota, for providing illustrations and helpful comments.

---

Hay, C., and T.P. Trooien. 2012. Managing high water tables and saline seeps in wheat production. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.





## CHAPTER TWENTY-ONE

# Field Scouting Basics

Darrell L. Deneke ([Darrell.Deneke@sdstate.edu](mailto:Darrell.Deneke@sdstate.edu))

Field scouting provides information needed to make the “best” possible in-season crop management decision. Regular and planned field scouting provides information on pest pressure, crop injury, crop growth staging, and soil and plant nutrient conditions. Field scouting, along with good field records, provides a resource for future management plans. This chapter discusses the basics of field scouting for weed, insect, and disease management.

### *Introduction and background*

Field scouting is a basic component of integrated pest management (IPM). Field scouting can be performed by 1) the grower, as a do-it-yourself option; 2) a field scout, or crop consultant, under contract; or 3) commercial ag-service personnel or agronomist. Developing a complete field history provides growers with information needed to minimize misdiagnosis and make the “best” decision possible. A “good” set of field records will include:

1. Specific field location (GPS information).
2. Crop data from the previous 1-3 years (variety information, pesticide applications) at a minimum.
3. Production year variety or hybrid.
4. Agronomic practices (planting date, planting rate, row width, tillage, timing of tillage or no-till).
5. Pesticide applications (rates, pesticide name, application dates, seed treatments).
6. Weather patterns.
7. Fertility application information.
8. Soil test results.
9. Soil type.
10. Pest information.

The right equipment helps to make the scouting job much easier. A good scouting report form and a clipboard are used to record the collected data. Other useful items are listed below (Table 21.1) as well as in the “Rules of Thumb for Scouting.”

**Table 21.1. List of helpful items for the field scout.**

1. Bucket	10. Sharp pocket knife or single-edged razor blade
2. A good sweep net (15" opening)	11. Clear plastic zip-lock type bags or screw-top vials
3. Drop (beat) cloth (2 ft long)	12. Alcohol
4. Hand lens - 10X	13. Forceps or tweezers
5. Measuring wheel	14. Travel or hand spade
6. Sampling square	15. Shovel
7. Tape measure or yard stick	16. Soil sampler
8. Field flags	17. Paper bags
9. GPS	

Scouting frequency will vary according to crop, crop stage and pest severity. In general, scouting should be done weekly during the growing season. When pest infestations approach economic levels or when weather conditions favor rapid development of specific pests, daily monitoring is recommended.

The number of samples for a field is dependent on the specific pest and other factors, which are noted in the “Rules of Thumb for Scouting.” Refer to information on the pest for economic thresholds and specific scouting patterns.

#### **Rules of Thumb for Scouting**

- Sample 5 locations within an area with a maximum size of 40–60 acres, sample “like with like.”
- Follow standard protocols when collecting information.
- Scouts need to be familiar with the growth and maturity stages of the crop (Chapter 3).
- To determine the wheat growth stage, scouts should collect a random sample of 10 plants around each sampling point (Fig. 21.1, 21.2, and 21.3).
- Scouts need to be familiar with the pest life cycle.
- Archive information for later assessments.

Landscape characteristics and information from field history should also be considered in the process of identifying sampling areas. If the field was in two different crops last year and one crop during the current year, it should be subdivided according to last year’s crop areas. The number of scouting stops needs to be representative of the field, and specific sampling units will vary according to the pest spatial and temporal variability.

Sampling methods need to be set up according to the pest and the crop. Sampling options could include swings of a sweep net for a specific area, insects on a drop or beat cloth, insects on leaf or other specific plant parts, disease symptoms on plant tissue, and/or weeds per row length (100'), or some systematic measure of land area.

A common method for counting insects is using a sweep net. To use a sweep net, swing the net from side to side in a full 180-degree arc. Tilt the net opening so that the lower edge of the rim is slightly ahead of the upper rim to catch insects as they fall from the plants. Sampling data is generally reported as average number of insects per sweep.

Some insects are easier to count if they are dislodged from the plants by shaking and allowing the insects to fall into a bucket or onto a white drop cloth or beat cloth. This works well, especially for insects that have coloration that blends in with the crop foliage. The cloth can be unrolled on the ground and placed between rows. Plants on both sides of the row are vigorously shaken to dislodge the insects. The same procedure can be done with a white bucket, and counts are documented as insects per plant.

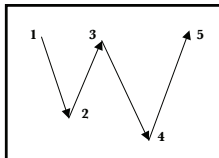
The most common means of sampling (scouting) small grain plants in the field is through visual observation, which works well with many insects and diseases. Specific plants samples can be taken and visual observation of insect and insect stages can be used to predict pest severity and development. Plant nutrient symptoms can also be detected through observation, and plant samples can be taken for analysis. Refer to your pest information sources for specific sampling procedures and economic thresholds.

Scouting patterns in the field units will help to ensure that the sampling results are representative of the whole field. There are several possible data collection and observation patterns that can be used when scouting fields. These are based on various pest distribution patterns and field layout configurations. As with the sampling options, scouting patterns are specific to pests and soil fertility problems. The three most common field scouting patterns are described below.

### ***Scouting patterns***

#### ***Pattern I.***

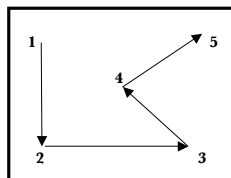
Use the W the pattern when scouting for pests that are uniformly distributed throughout the field (Fig. 21.1). The sampling sites should be evenly distributed across the field excluding obvious influencing factors such as field edges, hills, and low-lying areas. Common patterns typically look like an X, Y, W, or Z. Common pests that fit this pattern include wild oats, leaf diseases, aphids, and armyworm.



**Figure 21.1. A W sampling pattern.** Most appropriate for pest that are uniformly distributed across a field.

#### ***Pattern II.***

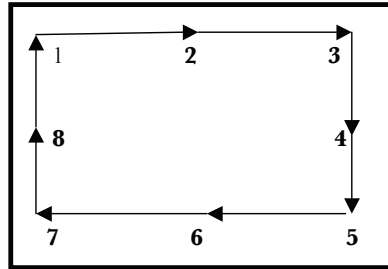
This pattern is used to target pests that favor specific characteristics such as highlands, lowlands, excessively wet or dry areas, or areas high in organic matter (Fig. 21.2). The sampling should be concentrated in the likely areas. Some examples of pests that fit this pattern include quackgrass, root rots, and cutworms.



**Figure 21.2. A targeted sampling protocol.** Appropriate for pests that favor specific characteristics.

### *Pattern III.*

This pattern is used when pests are at the edges of fields (Fig. 21.3). Sample for these pests by walking along the field edges, fence lines or ditches. Examples of pests that fit this pattern include grasshoppers, flea beetles, cheatgrass and Canada thistle.



**Figure 21.3.** A sampling protocol designed to identify pest invasions from adjacent fields.

### *Other considerations*

When scouting for insects, the objective is to identify the insects present in that field and determine which ones may become a problem. It is very important to determine the insect species and refer to local information on life cycles and economic thresholds so a decision on action can be made. It is helpful to be aware of the presence of any beneficial insects and to estimate if they are influencing the pest population. The beneficial insects may be able to keep the insect pests in check on their own. It is important to check fields at least weekly and more often if problem insect pest populations are building. Some insects can cause major damage in just a day or two.

Often fields can be scouted concurrently for insects, weeds, and diseases. When scouting for crop diseases, be aware of the disease symptoms, which are common to the area. Plant diseases in wheat can be influenced by weather, fertilizers, nutrient deficiencies, herbicides, and soil problems. In many cases, the cause of the symptom may not be obvious and may require samples to be taken to a diagnostic laboratory.

As with insects, disease scouting may require specific sampling techniques. Refer to your pest information source for specific problems.

The goal of weed scouting is to assess/monitor the infestation level in the field and to detect any new weeds. When new weeds show up, even at low levels, it should be noted so action can be taken to control or prevent them from becoming a concern. Many times early detection of a new weed problem will allow control strategies so as to prevent major problems later.

Scouting for weeds should begin early in the spring as new growth begins and continue until freeze-up in the fall. Weeds will compete with the crop for sunlight, space, moisture, and nutrients and, in sufficient numbers, may decrease the crop yields. A final scouting in the fall before snow cover will identify existing winter annual weeds, which will be the first to emerge the next spring; these weeds can be very competitive with both winter and spring wheat.



#### Additional information and references

Bissonnette, S.M., N.R. Pataky, E.D. Nafziger, V. Davis, K.A. Estes, D. Jones, M.E. Gray, C.A. Bradley, T. Niblack, and A.G. Hager. 2010. *Field crop scouting manual*. X880e. University of Illinois, University of Illinois Extension, Champaign, IL. Available at <https://pubsplus.illinois.edu/X880e.html>

Edwards, C.R., J.L. Obermeyer, T.N. Jordon, G.E. Shaner, J.M. Ferris, J.S. Loven, and L.W. Bledsoe. Revised 2001. *Field crops pest management manual*. Purdue University, Purdue University Cooperative Extension Service, West Lafayette, IN. Available at [www.ces.purdue.edu/extmedia/ent.htm](http://www.ces.purdue.edu/extmedia/ent.htm)

Fishel, F., W. Bailey, M. Boyd, B. Johnson, M. O'Day, L. Sweets, and B. Wiebold, B. Revised 2009. *IPM – introduction to crop scouting*. IPM 1006. University of Missouri, University of Missouri Extension, Columbia, MO. Available at [extension.missouri.edu/explorepdf/agguides/pests/IPM1006.pdf](http://extension.missouri.edu/explorepdf/agguides/pests/IPM1006.pdf)

Willson, H.R. 1990. *IPM field scouting*. FCPM Circular #2. The Ohio State University, Ohio State University Extension, Columbus, OH. Available at [ohioline.osu.edu/icm-fact/fc-02.html](http://ohioline.osu.edu/icm-fact/fc-02.html)

#### Acknowledgements

Support was provided by USDA through the IPM program.

---

Deneke, D.L. 2012. Field scouting basics. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.





## CHAPTER TWENTY-TWO

# Insect Pests of Wheat

Sue Blodgett ([sblodg@iastate.edu](mailto:sblodg@iastate.edu))

Jon Kieckhefer

This chapter discusses the important insect pests of wheat grown in South Dakota—the life cycles, plant damage, and possible management strategies. Included are wheat stem sawfly, brown wheat mite, Hessian fly, armyworm, wheat curl mite, wireworms, plus aphids including greenbug, and the Russian wheat aphid.

The High Plains Integrated Pest Management Guide has updated biological information, photographs, and pest recommendations for many crops including small grains.

[wiki.bugwood.org/HPIPM](http://wiki.bugwood.org/HPIPM)

### **Wheat Stem Sawfly (*Cephus cinctus*)**

Wheat stem sawfly has been a serious but regional pest of both spring and winter wheat grown in the Northern Plains and the Canadian Prairie Provinces for more than 100 years. Recently, this pest has spread into the Northwest and North Central areas of South Dakota. Wheat stem sawfly was first reported as a pest of spring wheat in the Canadian Prairie Provinces, increasing in economic impact until a resistant variety cv. 'Rescue' was developed. Resistance was based on a solid, pith-filled stem that protected the plant from successful insect colonization, preventing sawfly infestation. Over the past twenty years, sawfly has increasingly been found infesting winter wheat. Subsequently, resistant winter wheat varieties were developed by Dr. Phil Bruchner at Montana State University.

Early USDA-ARS surveys detected sawfly in western South Dakota at ~10%; however, more recent surveys have found infestations up to 60% in Northwestern South Dakota. Grower surveys in Montana in the mid 1990s estimated the economic impact of wheat stem sawfly at \$25 million per year. In North Dakota, a 2009 survey found crop loss due to wheat stem sawfly ranged from 10 to 25%; estimated crop losses between \$25 to \$70 million dollars. Wheat stem sawfly is a damaging pest of wheat affecting both yield and quality. Increased incidence of this pest in South Dakota is of concern.



**Figure 22.1. Wheat Stem Sawfly.** (Photo courtesy of Frank Peairs, Colorado State University, Bugwood.org. Illustration courtesy of Art Cushman, USDA. Property of the Smithsonian Institution, Dept. of Entomology, Bugwood.org)

### *Identification and lifecycle*

Wheat stem sawfly eggs are laid singly within the stem (Fig. 22.1). They are football-shaped and less than  $\frac{1}{16}$ " in length, but can be seen by eye when a stem is split. Multiple eggs may be laid within an elongating stem; however, cannibalism among larvae ensures that only one larva survives in a single stem. Pre-boot stage and larger diameter stems are preferred for egg deposition.

Newly-hatched larvae are pale and begin feeding on the stem pith passing through 4 or 5 instars before reaching maturity at approximately  $\frac{3}{4}$ ". Larvae can be detected when stems are split and a white-bodied larva with a dark head capsule emerges taking an 'S' shape when released from the stem. As the grain stem dries, larvae move to the base of the stem and cut a V-shaped notch that girdles the stem from within. There is an increasing tendency for the notched stem to snap cleanly off as it dries and becomes more brittle, resulting in lost grain heads. Consequently, the combine is unable to pick up the 'cut' stems during harvest. Larvae plug the stem below the notch forming a 1- to 2-inch 'stub,' spin a cocoon within the stub, and overwinter as larvae. The larvae overwinters in the cocoon, insulated by the soil, and pupates in the spring for approximately two weeks, before adults emerge in June.

Adult wheat stem sawflies emerge from the previous year wheat stubble by chewing through the plugged stub. Adults are dark and slender, approximately 1 inch in length, with yellow markings on the abdomen. Generally, mating occurs immediately upon emergence, though females do not need to mate in order to produce viable eggs that produce males; fertilized eggs become females. Adults are not thought to be strong fliers but can readily move to nearby fields to mate and lay eggs. Wind will also aid adult dispersal. When adults are present, they are not difficult to see. Detection is aided by using a standard sweep net.

Wheat stem sawfly adults are short-lived (7 to 10 days). Emergence may occur over a 4- to 6-week period depending on environmental conditions. Female sawflies deposit eggs into wheat stems from stem elongation to boot. The developing larvae pass the remainder of their life cycle within a wheat stem, providing limited management opportunities.

### ***Plant damage***

Wheat stem sawfly larval feeding causes a 17% yield reduction in cut stems and an 11% reduction in uncut stems (Holmes 1977). In addition to direct feeding by larvae, grain is also lost by lodging. Sawfly feeding can also reduce the protein content of the grain. A grower survey conducted in Montana estimated that \$25 to \$30 million dollars are lost each year to sawfly infestation (Blodgett et al. 1997). Additional economic consequences are damage to machinery as producers reduce the height of the cutting, slower harvest speeds, and the increased charges added by custom cutters when sawfly damage is evident.

Spring wheat, winter wheat, and durum wheat are the main cereal crops attacked by wheat stem sawfly, though infestations in other small grains such as barley, triticale, spelt, and others have been observed. Wheat stem sawfly does not complete their life cycle on oats. Wheat stem sawfly also survives on a number of grasses including species of *Agropyron*, *Bromus*, *Elymus*, and *Elytrigia*, in addition to cereal crops.

### ***Management***

Insecticides have not provided consistent control for wheat stem sawfly. Cultural controls such as burning, tillage, and trap cropping offer some control but are not compatible with production practices in all parts of the region. Conservation of biological control agents by raising cutting heights or using a stripper-header on the combine can be factors in helping to manage wheat stem sawfly on an area-wide basis. Planting resistant/tolerant cultivars offers the most consistent and satisfactory results. Currently, resistance/tolerance is based on solid stem varieties, stems that are filled with pith. Research continues to find additional sources of resistance and improvements to the cultural methods mentioned.

## CUTWORM SPECIES

In South Dakota two major cutworm species that damage wheat are the pale western and the army cutworm. Outbreaks can occur when cutworm populations are high and weather conditions are favorable for survival. However, outbreaks do not necessarily occur in successive years.

### **Army Cutworm (*Euxoa auxiliaris*)**

The army cutworm is a native of North America with damaging populations that change each year through migration within its distribution. The adult is a strong flier annually migrating each summer to high elevations (ca. 10,000 ft) in the Rocky Mountains.

#### ***Identification and life cycle***

The army cutworm has one generation per year. The adult stage is a moth that varies in color from light to dark gray-brown. In late summer and fall, the moth returns to the Great Plains mating and laying eggs in the soil. Egg hatch is triggered by moisture in the fall and early winter; larvae are the overwintering stage of the insect. Dry periods during August through October are detrimental to egg hatch and survival of newly hatched army cutworm larvae.

Larvae feed during late fall and winter on perennial and fall seeded crops, such as alfalfa and winter wheat. The larvae feed at night, spending their days resting beneath the crop residues or in the soil. In Colorado, army cutworm damage to winter wheat or alfalfa generally occurs in the fall, whereas in South Dakota and Montana, damage typically occurs in the early spring. When larvae are abundant and food is in short supply, they will move en masse, ‘army style’ to adjacent fields, hence the name army cutworm.

After larval feeding is complete, a pupal chamber is constructed within the soil. Moths emerge in May and June and migrate hundreds of miles to higher elevations in the Rocky Mountains to escape high summertime temperatures. At this stage, army cutworm moths are also the ‘millers’ that become a household nuisance during their migration.

#### ***Monitoring***

On clear sunny days, they can be found just below ground by scraping away the soil surface or by sieving soil through a mesh screen. Larvae of both species are well-camouflaged and difficult to detect in soil. Both methods are time and labor intensive and treatment decisions are often based on detection and characteristic plant damage, though thresholds are available in the *High Plains IPM Guide*. Bare spots in the field should be examined to differentiate winterkill from potential cutworm damage. Larvae may be detected more readily on the edge of a damaged or bare area.

#### ***Sidebar***

The army cutworm has an interesting biology that affects management. Adult moths aggregate during the summer at high elevation sites, in shaded locations under stumps, logs and other structures that offer protection. Wildlife researchers report that these dense aggregations of cutworm moths are an important food source for grizzly bears. Grizzly bears have been observed returning to army cutworm aggregations sites and feeding during July and August when other food sources are limited.

### ***Plant damage***

Army cutworms have a very wide host range and will feed on most crops grown, but are especially damaging to perennial or fall-seeded crops, crop plants present when larvae are active. This species is a climbing cutworm, moving up the plant at night or on cloudy days to feed on leaf tissues. While some leaf feeding may be tolerated, extensive feeding may cause unrecoverable plant death. In South Dakota, the army cutworm is primarily a pest of winter wheat and alfalfa with damage occurring in early spring.

### **Pale Western Cutworm (*Agrotis orthogonia*)**

The pale western cutworm has a range that includes the Great Plains through the western U.S. and southern Prairie Provinces (Fig. 22.2). The pale western cutworm does not migrate like the army cutworm and its populations may build up in an area if environmental conditions are favorable.

### ***Identification and life cycle***

Adults fly during August through early October mating and laying eggs in the soil. The egg is the overwintering stage of this insect, hatching in the spring. Pale western cutworm larvae feed and remain below ground through the life stage and are difficult to monitor because of their subterranean habit. The pale western cutworm is grayish-white in color, unmarked by spots or stripes, with two distinct vertical brown bars on the front of the head capsule. A fully developed larva is about 1" in length.



**Figure 22.2. Pale western cutworm, top and Army cutworm, bottom.** (Photo courtesy of University of Nebraska Department of Entomology)

Pale western cutworm larvae begin feeding later in the spring than the army cutworm and are therefore primarily a pest of spring wheat. Dry weather favors the successful development of the pale western cutworm. However, spring rains are unfavorable to newly-hatched pale western cutworm larvae. The risk of an outbreak decreases with increasing number of wet days, > 0.25 inch of precipitation (Hein et al. 2006). If May and June have fewer than 10 days with 1/4" or more of rainfall, then pale western cutworm populations can be expected to increase. If May and June have more than 15 'wet' days, then cutworms will almost totally disappear. Rainfall events of more than 1/4" tend to drive the cutworms to the soil surface, which exposes them to predation and parasitism.

### ***Plant damage***

Small grains, corn, and a variety of other crops have been damaged by pale western cutworm. The pale western cutworm is the more damaging of the cutworm species, because it chews through the stem, killing the plant and reducing plant stand.

### ***Management***

Because of the sporadic nature of army cutworm outbreaks, management options are limited to the use of insecticides. Treatments are warranted if more than 2 to 4 army cutworm larvae per ft<sup>2</sup> are detected. The treatment threshold for pale western cutworm



is lower, however, because they are the more damaging. The economic threshold for pale western cutworms is 1 to 2 larvae per ft<sup>2</sup>. For both cutworm species, pyrethroid insecticides have been very effective.

### **Brown Wheat Mite (*Petrobia latens*)**

Brown wheat mite, a pest of wheat and barley, is of particular concern during dry weather periods primarily in western South Dakota. An image for the brown wheat mite can be found at <http://www.ento.okstate.edu/ddd/insects/brownwheatmite.htm>.

### ***Identification and life cycle***

Mites are tiny, spider-like creatures with four pair of legs and they are about as big as the period at the end of this sentence. Mites are oval with dark red-brown bodies and lighter yellow-orange legs; the front legs are about twice as long as the other three pairs of legs. Unlike mite species that produce webbing, the brown wheat mite is free-living without webbing. In spring and early summer, mites lay red eggs that hatch after a short period of time, producing multiple generations. However, as the season progresses, female mites begin to produce white eggs that remain dormant until fall. The white eggs are a resting stage indicating that mite activity is declining.

### ***Plant damage***

Brown wheat mites move from the soil to the host plant to feed on foliage. Feeding produces a fine white speckling called stippling, which is caused by the removal of chlorophyll from each feeding site. Stippling typically coalesces causing the leaves to turn light green to white colored and droughty in appearance; mite damage is often confused with symptoms of drought stress. Brown wheat mites are known to damage a wide variety of cultivated plants including alfalfa, wheat, clover, and other small grains.

### ***Monitoring***

Mites are difficult to monitor because of their small size and lack of webbing. However, their presence can be detected with the aid of a hand lens or by tapping foliage over a white paper and counting the just visible, dislodged mites, which appear as small brown spots that smear orange-brown. Volunteer wheat is an important reservoir for brown wheat mites (and other arthropods) and should be examined when weather conditions favor mite population development.

*The economic threshold for this pest is not well defined but treatment is not profitable unless there are at least several hundred mites per row foot in the early spring.* It is often difficult to justify a chemical treatment, since brown wheat mite infestations are associated with drought stress. Mite treatment may not be economical if yield and/or quality are compromised by drought stress.

### Management

Moisture in the form of rainfall or irrigation will dramatically reduce mite populations; a driving rain of at least  $\frac{1}{3}$ " will reduce populations. If white eggs are present, the population is entering a dormant state and treatment is not justified. Management of volunteer wheat is an important preventive measure for brown wheat mites and other small grain pests. However, once an outbreak occurs, chemical control is the only effective (albeit temporary) management option.

### Hessian Fly (*Mayetiola destructor*) (Say)

Hessian fly has been increasing in many Midwest states and has been found in South Dakota, though damaging populations are not common (Fig. 22.3 and 22.4). It is thought that recent population increases are related to increased adoption of no till.



**Figure 22.3. A Hessian fly on a leaf.**

(Photo courtesy of University of Nebraska Department of Entomology)



**Figure 22.4. Larval Hessian flies.**

(Photo courtesy of University of Nebraska Department of Entomology)

### Identification and life cycle

Adult flies resemble a dusky mosquito and are approximately  $\frac{1}{8}$ " in length. Hessian fly overwinters within a 'flaxseed'-like structure found in wheat crop residue from which the fly emerges in the spring. Typically Hessian flies in the Great Plains have an early spring generation and a summer generation that overwinters on wheat stubble. Adults emerge and mate in the spring, laying their orange-red colored eggs on the upper surface of the leaf blade parallel to the leaf veins. Upon hatching, the larvae move to the leaf sheath where they are protected from dry environmental conditions. When feeding is completed, the larvae move lower on the plant forming the flaxseed. Highly infested plants may have up to 20 or more Hessian fly 'flaxseeds' on the crown of one plant.

### ***Plant damage***

Hessian fly maggots feed by rasping plant stems and sucking plant juices that ooze from the damaged stem surface of wheat and barley. While feeding, they introduce a plant toxin that causes plant tissues near the feeding site to be stunted and misshapen. Leaves may appear thickened, erect, and bluish green in color. The stem that the maggot feeds on often has a reduced or no grain head, and the stem may be deformed and/or weakened at the point of feeding. As the plant matures and tissues dry, the weakened Hessian fly feeding site is prone to breakage.

Hessian fly damage is detected through careful plant inspection before stem breakage at or before harvest. A new pheromone has been developed that may be used for detection (M. Harris, North Dakota State University). Infestations of less than 10% stems, with one flaxseed per stem, are estimated to reduce yields less than one bushel per acre (Whitworth et al. 2009).

### ***Management***

Resistant varieties are not currently available for this pest. Although there are known parasitic wasps of Hessian fly, there are no management practices for conserving parasite populations.

Undisturbed stubble favors Hessian fly survival. Studies have shown that when infested plant material containing the flaxseed stage are buried 1 inch deep (by tillage), there was 26% fly emergence; at 2 inches, only 6% of the population emerged; and at 4 inches, none emerged (Whitworth et al. 2009).

Volunteer wheat stubble favor Hessian fly populations by providing additional host plant material. Additionally, destroying volunteer wheat provides protection from wheat curl mite, brown wheat mite, and aphid species. In South Dakota where both spring and winter wheat crops are planted, and Hessian fly pressure is sporadic, agronomic considerations outweigh Hessian fly management. Crop rotations that avoid continuous wheat may help to break the cycle.

Seed treatments may control Hessian fly for up to 30 days, but are only recommended in states when consistent populations are present and economic damage is expected. Seed treatments are not recommended in South Dakota because the Hessian fly populations are sporadic.

## ***Armyworm (*Pseudaletia unipincta*)***

### ***Identification and life cycle***

Armyworm is a sporadic South Dakota wheat pest (Fig. 22.5). Mature armyworms can reach 1½" length, have smooth-bodies, and range in color from green to brown with longitudinal stripes down the back. Black markings on the head capsule are characteristic of this pest.

The armyworm is unable to survive South Dakota winters. They overwinter in the southern portion of their range, migrating north in early summer when environmental conditions are favorable. Pheromone traps can be used to monitor the moth's presence. Female moths deposit eggs in rows or clusters on the lower leaves of various grass crops. Dense grassy vegetation is preferred for oviposition.



**Figure 22.5. Armyworm larva.**  
(Photo courtesy of David Keith, University of Nebraska Department of Entomology)

### ***Plant damage***

Armyworm feeding is mostly limited to grasses, although this insect will feed on a number of other host plants when starved. Larvae feed at night and on cloudy days, feeding on plant foliage, defoliating plants. During the day, larvae remain protected under crop debris. One or more generations may occur per year. In Colorado, armyworm is mostly a pest of corn and spring grains, with only occasional infestations occurring in winter wheat. In Wyoming, grass hayfields are periodically damaged.

### ***Monitoring***

Armyworm moths should be scouted on the field margins, low areas with excessive (rank) growth, or areas of lodged plants (Chapter 21). Look for feeding damage (defoliation), frass (droppings) around the base of the plant, head clipping, or plant tillers that have been clipped by armyworm feeding. Check for larvae in and under debris around damaged plants and in heads of wheat or barley. Migration to an area may be detected by using pheromone traps to monitor adult activity.

### ***Management***

Armyworm outbreaks are sporadic due to the migration of armyworm adults into the state. Because of the sporadic and unpredictable nature of armyworm outbreaks, management options are limited to the use of insecticides.

## **Wheat Curl Mite (*Aceria tosichella*)**

### ***Identification and life cycle***

The wheat curl mite is approximately  $\frac{1}{100}$ " in length and can be viewed with a hand lens. The mite completes its life cycle in 8 to 10 days passing through two nymphal stages before reaching the adult stage. Adults do not fly but because of their light weight, are carried on air currents and wind. Mites have multiple and overlapping generations and all stages are able to overwinter on green plant material and crop residues with the capacity to build up large populations when temperature and moisture are favorable.

Mites are more frequently found at the base of a wheat leaf on the upper leaf surface in the depressions between leaf veins, under the leaf sheath, or within the head. Wheat curl mite has several cultivated and non-cultivated grass hosts. An image of wheat curl mite is available at <http://www.ento.okstate.edu/ddd/insects/wheatcurlmite.htm>.

### ***Plant damage***

Wheat curl mite is a vector of wheat streak mosaic virus and other closely related viruses. Mites pierce plant tissues and suck juices, causing leaves to roll and the virus to be introduced. Symptoms of the wheat streak mosaic are discussed in Chapter 23.

Several sweet corn varieties and a few field corn hybrids are susceptible to wheat streak mosaic virus disease. Susceptible sweet corn varieties and hybrids can harbor mites and the virus can move into and infect winter wheat.

### ***Monitoring***

Wheat curl mites are difficult to detect because of their small size. Volunteer wheat should be inspected for mites because it provides a 'green bridge' for mite populations. The green bridge enables mites to move between crops and can infest early seeded winter wheat crops.

### ***Management***

Cultural controls that break the green bridge are the most effective and economical methods of managing the wheat curl mite and wheat streak mosaic. When conditions favor the wheat curl mite, the mite or symptoms of wheat streak mosaic are present. Actions such as volunteer wheat control and delayed planting of fall winter wheat can reduce the impact on the subsequent wheat crop. A good mitigation strategy is to avoid planting alternative and/or susceptible hosts such as sweet corn, foxtail millet and other grass crops that can act as green bridge crops. Mites require green plant tissue to survive and, therefore, breaking the green bridge can reduce its impact. Chemical control of the mite has not been shown to be consistently effective.

## **Wireworms (Coleoptera: Family Elateridae)**

Wireworms may require several years to complete their life cycle and are the larval stage of the click beetles.

### ***Identification and life cycle***

Adult click beetles are brown to black in color, elongate and their thorax is structured such that an audible click is heard when adults arch their back to right themselves. Females deposit eggs in the soil among grass roots in the spring. Initially, small larvae are white, but later mature stage larvae develop harder (sclerotized) plates that are yellow to red brown in color (Figure 22.6). Mature larvae range from ½" to 1" in length.

Larvae feed on the roots of corn and other grasses, including wheat. They are very sensitive to soil moisture and temperature, moving up into the root zone in the spring in response to warming soils and adequate moisture. As soil moisture levels decrease and soil temperatures warm, larvae move deeper into the soil. Life cycles of wireworm species range from one to five years, moving within the soil profile to feed and pupating once the larval stage is complete. The insects overwinter in the soil.



**Figure 22.6. Wireworms, larvae of elaterids.**  
(Photo courtesy of University of Nebraska  
Department of Entomology)

### ***Plant damage***

Wireworm larvae are associated with grassy vegetation. Cropland that is established on former grasslands or continuously cropped to crops in the grass family is at risk for wireworm damage. Feeding occurs in the early spring when wireworms move into the root zone in response to favorable soil temperature and moisture conditions. Larvae feed on seed, roots, and underground stem tissue. Seedling plants may be killed and plant stands reduced. Poor seedling emergence, root feeding, and uneven stands can be symptoms of wireworm damage. Winter damage may be confused with wireworm damage.

### ***Monitoring***

Wireworms can be monitored pre-plant by collecting soil samples or by establishing solar bait stations. Stations are baited with approximately  $\frac{1}{2}$  cup (4 oz) of soaked grain (to speed germination) that attract larvae. The bait is placed in the soil and covered with mounded soil. The mound is covered with clear plastic to warm the soil around the bait station and attract wireworms. Bait stations are excavated in 7 to 10 days to assess wireworm populations (Wright et al. 2006).

### ***Management***

Insecticide seed treatments are the most effective strategy for controlling wireworms. Foliar treatments are not effective in managing larvae that feed and reside below ground.



## APHID SPECIES (APHIDIDAE APP.)

Several species of aphids can have important impacts on wheat production in South Dakota. The more damaging species are virus vectors and/or inject plant toxins that cause damage that is disproportionate to their numbers. Typically, aphid populations in South Dakota occur as an aphid complex.

### Bird Cherry Oat Aphid (*Rhopalosiphum padi*)

This species is one of the most common and damaging species in South Dakota and the vector of the barley yellow dwarf virus. Additional information about this disease is available in Chapter 23.



**Figure 22.7. Bird Cherry Oat Aphid.** (Photos courtesy of David Cappaert, Michigan State University and Frank Peairs, Colorado State University, Bugwood.org)

### Identification and life cycle

The bird cherry oat aphid ranges in size from  $\frac{1}{32}$ " to  $\frac{1}{16}$ ", and is dark green to olive green in color. The key feature distinguishing this species is the red-orange patch at the base of the cornicles (tailpipes). Aphids have multiple and overlapping generations throughout the growing season, enabling populations to increase rapidly when temperatures are favorable. The bird cherry oat aphid overwinters in the egg stage on *Prunus* species hatching and migrates to cereal crops in late spring to early summer. Populations are often abundant in fall on winter wheat crops.

### Plant damage

Aphids have piercing-sucking mouthparts and damage plants by removing plant nutrients; however, significant damage by this species is caused by the virus it vectors, barley yellow dwarf virus (BYDV). BYDV causes stunted plants, small heads, and shriveled kernels resulting in reduced yields. Production of the honeydew that aphids excrete can interfere with grain harvest.



### **Monitoring**

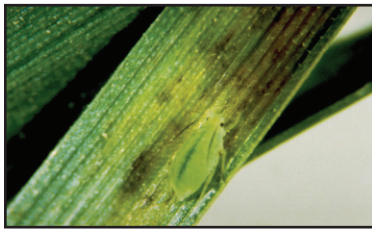
Aphids can be monitored by plant inspection assessing the number of aphids per stem and the percentage of infested plants. These assessments are based on the economic thresholds for aphid species. Although aphids can be rapidly detected using a sweep net, treatment decisions are based on the more rigorous aphid/plant assessments.

### **Greenbug (*Schizaphis graminum*)**

Greenbug is a true aphid and damages both by direct feeding and by injecting a toxin into the plant that causes additional plant damage.

### **Identification and life cycle**

The greenbug is a small aphid and ranges in size from  $\frac{1}{16}$ " to  $\frac{1}{8}$ ". It is light green in color and has a dark green stripe down its back. The legs and cornicles are also light in color. Aphids have multiple and overlapping generations throughout the growing season, enabling populations to increase rapidly when temperatures are favorable. This species is also a pest of sorghum, and small grains in proximity may experience migration between these preferred crops. The greenbug overwinters in the egg stage, hatching and migrating into cereal crops during spring and early summer.



**Figure 22.8. Greenbug.**  
(Photos courtesy of Alton N. Sparks Jr., University of Georgia and Frank Peairs, Colorado State University, Bugwood.org)

### **Plant damage**

Aphids have piercing-sucking mouthparts and damage plants by removing plant nutrients and injecting a plant toxin causing leaves to turn yellow. Symptoms may be confused with nitrogen deficiency moisture stress, but the presence of this species allows these factors to be differentiated. Greenbug also vectors barley yellow dwarf virus.

### **Monitoring**

Aphids can be monitored by plant inspection assessing the number of aphids per stem and the percentage of infested plants. These assessments are based on the economic thresholds for aphid species. Although aphids can be rapidly detected using a sweep net, treatment decisions are based on the more rigorous aphid/plant assessments.

### Russian Wheat Aphid (*Diuraphis noxia*)

This species is one of the most damaging species in western South Dakota because a plant toxin is injected into the plant during feeding.



**Figure 22.9. Russian Wheat Aphid.**  
(Photos courtesy of Frank Peairs, Colorado State University, Bugwood.org)

### Identification and life cycle

The Russian wheat aphid measures  $\frac{1}{16}$ " to  $\frac{1}{12}$ ", is a dusty blue-green in color, has shortened antennae, greatly reduced cornicles, and the appearance of a double caudal or tail when viewed from the side. The Russian wheat aphid is not able to survive the cold winter temperatures in South Dakota. Infestations of this species rely on migration from southern cereal production areas. Once present in the state, it has multiple and overlapping generations throughout the growing season. Russian wheat aphid, like other aphid species, can increase rapidly when conditions are favorable.

### Plant damage

Russian wheat aphid have piercing-sucking mouthparts that damage plants by removing plant nutrients. They inject a plant toxin causing leaf rolling accompanied by white streaks in leaves that may have some areas of purple discoloration. Rolled leaves trap the subsequent leaf or grain head creating a distinctive hooking of emerging plant tissue. These symptoms are characteristic of Russian wheat aphid infestation and can result in reduced grain yield when populations are sufficiently large.

### Monitoring

Aphids can be monitored by plant inspection assessing the number of aphids per stem and the percentage of infested plants. These assessments are based on the economic thresholds for aphid species. Although aphids can be rapidly detected using a sweep net, treatment decisions are based on the more rigorous aphid/plant assessments.

### ***Management***

Several natural enemies, both predators and parasitoids help to manage aphid populations. Species of lady beetles, lacewings, Syrphid fly, damsel (nabid) bugs, orius (minute pirate bug), lacewings, and assassin bugs are the major species of predators. There are several parasitic wasps that attack aphids causing the affected aphid to enlarge and harden to a mummy.

Controlling volunteer wheat, which can harbor aphid populations and provide a bridge between susceptible crops, is important to inspect regularly and manage as needed. Early planting of spring wheat and delayed planting of winter wheat can help avoid periods of increased risk of aphid infestation.

There are several insecticides that are effective in controlling aphid populations when treatment is warranted when the threshold is reached. The *High Plains Integrated Pest Management Guide* has biological information and updated pest recommendations for many crops including small grains/wheat. [wiki.bugwood.org/HPIPM](http://wiki.bugwood.org/HPIPM)

#### Additional information and references

Blodgett, S.L., G. Johnson, W.P. Kemp, and J.K. Sands. 1997. Developing an Extension pest management program using the needs-assessment process. *J. Extension* 35. <http://www.joe.org/joe/1997february/a1.php>

Buntin, G.D., K.S. Pike, M.J. Weiss and J.A. Webster. 2007. *Handbook of Small Grain Insects*. Entomological Society of America.

Flint, M.L. 1990. *Integrated pest management for small grains*. Publication 3333. University of California Agriculture & Natural Resources, UC IPM.

Hein, G.L., J.B. Campbell, S.D. Danielson, J.A. Kalisch. 2006. Management of the Army cutworm and pale western cutworm. NebGuide No. G1145. UNL, Cooperative Extension Service.  
Available at <http://www.ianrpubs.unl.edu/pages/publicationD.jsp?publicationId=554>

High Plains Integrated Pest Management. 2010. Available at [http://wiki.bugwood.org/Main\\_Page](http://wiki.bugwood.org/Main_Page)

Holmes, N.D. 1977. The effect of the wheat stem sawfly, *Cephus cinctus* (Hymenoptera: Cephidae), on the yield and quality of wheat. *Canadian Entomol.* 109:1591-1598.

Whitworth, R.J., P. Sloderbeck, H. Davis, and G. Cramer. 2009. Kansas crop pests: Hessian fly. No. MF-2866. Kansas State University, Agricultural Experiment Station and Cooperative Extension Service.  
Available at <http://www.ksre.ksu.edu/library/entml2/mf2866.pdf>

Danielson, S., R. Wright, G. Hein, L. Peters, and J. Kalisch. 2006. Insects that attack seeds and seedlings of field crops. NebGuide No. G1023. UNL, Cooperative Extension Service.  
Available at <http://www.ianrpubs.unl.edu/live/g1023/build/g1023.pdf>

#### Acknowledgements

Support was provided by South Dakota Wheat Commission and the South Dakota State University Agricultural Experiment Station.

---

Blodgett, S., and J. Kieckhefer. 2012. Insect pests of wheat. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.



## CHAPTER TWENTY-THREE

# Wheat Diseases in South Dakota

Connie L. Strunk ([Connie.Strunk@sdsu.edu](mailto:Connie.Strunk@sdsu.edu))

Buyung Hadi ([Buyung.Hadi@sdsu.edu](mailto:Buyung.Hadi@sdsu.edu))

Disease identification and management are integral parts of South Dakota's wheat production. Diseases can affect agronomic traits (such as growth and stand) and reduce yield. They also contribute to inferior seed, lower grain quality, and market rejection due to mycotoxin concentrations. The purpose of this chapter is to discuss how to recognize wheat diseases and possible management options.

### *Scouting and control principles for diseases*

Fungal, bacterial and viral pathogens cause critical diseases that reduce South Dakota wheat yields. The first step in diagnosing a problem is recognition. Thus, crop scouting is critical to assess the actual risk of a particular disease in the field. Scouting is the basis for integrated disease management and provides the information needed for when and where to apply chemical, cultural or biological control measures (Chapter 21). A wheat disease scouting calendar (Table 23.1), which includes a summary of management considerations, is located at the end of the chapter.

Fungicides are well-known methods of disease control (Osborne and Stein 2009; Ruden and Osborne 2011). Wheat fungicide management is most economical when:

1. Fungicides are used in response to actual disease risk rather than as a prescriptive application without a risk assessment; and
2. Fungicides are used as part of an integrated disease management strategy and not when they are the only control method.

Well-adapted disease resistant varieties (Hall et al. 2011) should be combined with good cultural practices such as crop rotation, disease-free seed, and optimal planting dates. Foliar fungicides are effective only in managing diseases caused by fungi and do not offer direct protection against bacterial or viral diseases, nematodes, or abiotic stresses.

To maximize the return on a fungicide application, select the least expensive fungicide with the highest efficacy on the target disease (when warranted). The North Central Regional Committee on Management of Small Grain Diseases, a working group of plant pathologists from north central universities, has developed an efficacy rating of commonly used fungicides based on field trials conducted across multiple years and locations. A summary of the latest efficacy rating trial (conducted in 2010) is given in Table 23.2, which is shown at the end of the chapter.

Foliar fungicide applications on wheat are most profitable if timed to protect the flag leaf, as the flag leaf contributes up to 75% of a producer's grain yield. In cases where disease pressure is high early in the growing season, it may be necessary to apply a fungicide before flag leaf emergence for early season disease suppression. The decision to apply a foliar fungicide depends on several factors including:

1. Favorability of the environment to disease development (disease risk).
2. Susceptibility of the variety planted to disease.
3. Fungicide application cost.
4. Yield saved due to fungicide application.
5. The market price of wheat.

Wise use of fungicides should also include rotation of the chemical class utilized in order to limit the development of pathogen strains with resistance toward a particular class of fungicide.

## FUNGAL DISEASES

There are many fungal diseases that can and do attack wheat, but only a few are routinely responsible for major economic losses. Foliar fungal diseases of primary concern include: tan spot, powdery mildew, stem rust, leaf rust, stripe rust, *Stagonospora* (*Septoria*) leaf blotch, *Fusarium* head blight or scab, and root rot diseases.

### ***Tan spot***

*Symptoms:* Infection may occur on all above-ground plant parts, but symptoms are most commonly found on leaves. The symptoms start as small brown freckles that grow into oval or lens-shaped lesions ( $\frac{1}{8}$  to  $\frac{1}{2}$  inch long and  $\frac{1}{16}$  to  $\frac{1}{8}$  inch wide) with prominent yellow halo and tan to dark brown centers (Fig. 23.1). Spots may coalesce forming larger necrotic areas (Fig. 23.2), and the leaves may eventually wither. Tan spot is usually more severe on lower leaves and then progresses upward.



**Figure 23.1. Tan spot on wheat.**  
(Image: Mary Burrows, Montana State University, Bugwood.org)



**Causal pathogen:** Tan spot is caused by the fungus *Pyrenophora tritici-repentis*. There are eight recognized races of *P. tritici-repentis*. Each race produces different host-selective toxins (HST) on susceptible wheat varieties and is often geographically distinct in distribution.

**Life cycle:** The causal pathogen of tan spot overwinters as pinhead-sized fruiting bodies called pseudothecia on crop residues in the field. During wet periods in the spring, ascospores are produced and released as primary inoculum. Infection occurs first on the lower leaves and spreads upward. As the disease progresses, conidia are produced on infected tissues and spread by wind for secondary infection. Kernels can be infected if heavy infection occurs on the flag leaves. Infected kernels can sometimes show red smudges on the surface. Damp (frequent rains) moderate temperatures (68–82.4°F, 20–28° C) are favorable for disease development. Infected plants usually produce smaller kernels. Yield loss can reach 50% in highly susceptible varieties.



**Figure 23.2. Coalescing tan spot lesions forming bigger necrotic areas.**  
(Image: Mourad Louadfel, Plant Protection, Bugwood.org)

**Management:**

- 1) Wheat varieties resistant to tan spot are available and effective in managing the disease.
- 2) Reduced tillage cropping system stands have an increased tan spot risk due to the pseudothecia on stubble and debris.
- 3) Removal or destruction of residues known to be infected by tan spot is effective in decreasing the tan spot risk in subsequent wheat seasons.
- 4) Crop rotations can reduce the inoculum pressure from tan spot in a given field. Rotate wheat with broad leaf crops since these crops are known as non-hosts of *P. tritici-repentis*. Corn is not a tan spot host, but planting wheat on corn residue may increase the risk of Fusarium head scab.
- 5) Planting pathogen-free seeds is recommended. Seedlings growing from infected seeds have reduced vigor. If seeds infected with the pathogen are planted, seed treatment can reduce the risk of seedling infection.
- 6) Foliar fungicides that are effective in suppressing tan spot are available. However, application of foliar fungicide is not always profitable. In situations where wheat is planted on the previous year's infected residue, a susceptible variety is used. When spring weather is warm and rainy, foliar fungicide may or may not be economically beneficial.

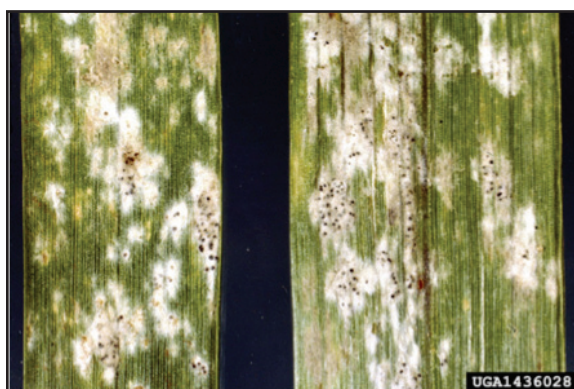
**Powdery mildew**

**Symptoms:** Powdery mildew-infected plants show numerous raised, white, powdery spots on the aerial plant surface (Fig. 23.3). These spots are, in fact, the vegetative strands (mycelium) and spore masses of powdery mildew colonies. As the colonies age, the spots may turn grey with cleistothecia (structures that produce sexual spores and help the pathogen survive during the winter) visible on them (Fig. 23.4). Powdery mildew is prevalent in the lower canopy and humid environments.



**Causal pathogen:** Powdery mildew on wheat is caused by *Blumeria graminis* f. sp. *tritici*. Several races of this pathogen exist.

**Life cycle:** Powdery mildew pathogen survives the winter in plant debris left on the field. Ascospores (spores formed in the cleistothecia) are produced in the spring to act as primary inoculum. The fungus produces structures (haustoria) that directly penetrate the plant tissue while maintaining a network of fine white mycelial filaments and spore producing structures on the plant surface. Conidia, a type of asexual spores, are produced on the surface of infected plants throughout the growing season, facilitating the disease spread. Temperatures between 60–70° F (15.5–21.1° C) with damp weather are favorable for powdery mildew buildup. Disease development is retarded when temperatures are higher than 77° F (25° C). High planting rate elevates the humidity within the lower canopy and increases disease development.



**Figure 23.3. Numerous raised powdery spots characteristic of powdery mildew on wheat.** (Image: Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org)



**Figure 23.4. Cleistothecia (the overwintering structure) produced on mature powdery mildew colonies.** (Image: Department of Plant Pathology Archive, North Carolina State University, Bugwood.org)

**Management:**

- 1) Deploying wheat varieties with resistance toward powdery mildew is critical. Wheat varieties differ significantly in their reactions to powdery mildew.
- 2) Since *B. graminis* overwinters on crop residues in the field, reduced tillage practices may increase the risk of powdery mildew infection. Destruction of volunteer wheat, tillage and crop rotations reduce the risk of powdery mildew infection.
- 3) Over fertilization with nitrogen may increase the risk of powdery mildew. Plants with increased nitrogen are more susceptible to powdery mildew. Nitrogen promotes tiller formation and, inadvertently, produces a favorable environment for powdery mildew development. Balanced fertilization regimes with proper levels of N, P and K should be utilized.

- 4) Foliar fungicides that are effective in suppressing powdery mildew are available. However, application of foliar fungicide is not always profitable. Conditions where wheat is planted on the previous year's infected residue, a susceptible variety is used and the weather is mild and humid are favorable for the disease and should be considered when making a decision on fungicide application.

## RUSTS ON WHEAT

Leaf rust, stem rust, and stripe rust affect wheat in South Dakota. These rusts have very complex life cycles requiring five spore stages. **Teliospores** overwinter on plant debris and soil and begin this complex life cycle in the spring when they germinate. **Basidiospores** (sporidia) are produced on germinating teliospores which then infect the leaves of the alternate host. Soon after very small pycnial pustules occur. Pycnia produce **pycniospores** and receptive hyphae. Once receptive hyphae of a pycnia are fertilized by pycniospores of the opposite mating type, mycelia grow through the alternate host leaf producing **aecia** (cluster cups) on the underside of the leaf. Aecia produce **aeciospores**, which are windborne and capable of infecting wheat plants. On wheat, aeciospores germinate and penetrate into the plant tissue. In a week or two, infecting mycelium starts to produce uredinia which bear **urediospores**. Urediospores are the only rust spores that are able to re-infect wheat plants throughout the growing season. As the plants mature, telia start to develop and teliospores form within the telia. Unfortunately, rust urediospores can also initiate infections on wheat when aeciospores are not present.

### *Leaf Rust*

**Symptoms:** Leaf rust pustules are orange to dark reddish-brown, raised, powdery, small (usually 1 mm or less in size), oval shaped, often found on the upper leaf surface (Fig. 23.5). Thousands of spores (contained in each pustule) are then dispersed by the wind. Using your finger you can distinguish rust pustules from other leaf spot diseases by rubbing (smearing) the colored spores on the leaf surface.

**Causal pathogen:** Leaf rust on wheat is caused by *Puccinia triticina* (*P. recondita* f. sp. *tritici*).



**Figure 23.5. Leaf rust pustules on wheat.**  
(Image: Ida Paul, Small Grain Institute, Bugwood.org)

**Life cycle:** Leaf rust has a complex life cycle involving five different spore types and two types of host: wheat as the primary host and meadow rue (*Thalictrum* sp.) as the alternate host. *Puccinia triticina* overwinter on infected wheat in the southern states and Mexico, and the urediospores, one of the spore types produced by leaf rust pathogen, are carried northward by the wind. Upon alighting on wheat leaf surface, moisture is required for urediospores to germinate and infect wheat leaves. If environmental conditions are favorable, a new generation of urediospores may be produced every 7 to 14 days. Light rain, high humidity, or heavy dew and temperatures ranging between 59° and 77° F (15–25° C) are ideal for rust development. Leaf rust continues to spread by means of wind-blown urediospores (from plant to plant and from field to field) until the wheat matures. *Puccinia triticina* does not survive the winter in the northern latitudes, and for the disease to start in any given year, new inoculum must be introduced from the southern latitudes.

#### **Management:**

- 1) Fungicide application is recommended to control leaf rust if the disease is established in the crop canopy and weather favors rust development prior to heading.
- 2) Many wheat varieties are resistant to the various rusts (Hall et al. 2011); however, the development of new races may break a variety's resistance.  
[http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/EC774-11.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC774-11.pdf)

### **Stem Rust**

**Symptoms:** Stem rust appears as dark orange to brick-red, raised, powdery pustules with ragged edges. Lesions are often large and can be found on stems and leaf sheaths (Fig. 23.6).

**Causal pathogen:** Stem rust is caused by *Puccinia graminis* f. sp. *tritici*.

**Life cycle:** Stem rust has a complex life cycle which requires a susceptible host (wheat and some varieties of barley, oats, rye, wild barley, and goat grass) and an alternate host (common barberry, *Berberis vulgaris*). It also produces five different spore types, produced in five different fruiting bodies, in order to complete its life cycle. Of these fruiting bodies and spore types, spermatogonia (pycnia) containing spermatia (pycniospores) and aecia containing



aeciospores are found on the alternate woody host. Uredia (which produce urediospores) and telia (which produce teliospores) are found on wheat or other grassy hosts. Stem rust overwinters as teliospores in colder climates and urediospores on fall-planted wheat in warmer climates. In South Dakota, wind-blown urediospores are carried upward from the southern latitudes and serve as primary inoculum for wheat infection. Stem rust infection can occur between 65–85° F (18.3–29.4° C) when free moisture is available (dew, light rain, humidity).

**Figure 23.6. Stem rust on wheat.**  
 (Image: William M. Brown Jr.,  
 Bugwood.org)

*Management:*

- 1) Plant resistant cultivars (Hall et al. 2011). Resistance is the primary means of control for stem rust. Remember, the emergence of new races require constant vigilance.  
[http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/EC774-11.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC774-11.pdf)
- 2) Eradicate woody hosts.
- 3) Fungicide application is usually not necessary or cost effective as long as resistant cultivars are used. If a new race is identified, than a fungicide application will be warranted.

### **Stripe Rust**

*Symptoms:* Small, yellow-orange pustules arranged in rows (stripes) on leaves of wheat (Fig. 23.7). Rows of pustules often resemble sewing machine stitches.

*Causal pathogen:* Stripe rust on wheat is caused by *Puccinia striiformis* f. sp. *tritici*.

*Life cycle:* Cool, wet weather favors stripe rust development. Rapid disease development occurs between 50° and 60° F (10–15.5 C) when moisture is available, while temperatures over 68° F (20° C) for several days in a row inhibits disease development. Stripe rust needs a green host (wheat, perennial grassy weeds) to survive and has been known to overwinter under snow cover as dormant mycelium. Stripe rust spores are blown into South Dakota from neighboring wheat-producing states to the south.



**Figure 23.7. Stripe rust on wheat.**  
(Image: Mary Burrows, Montana State University, Bugwood.org)

*Management:*

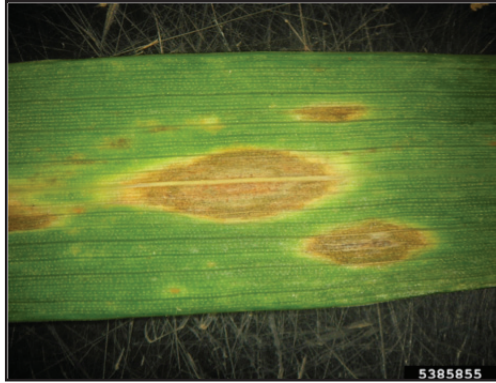
- 1) The use of cultivar resistant varieties is the main means of stripe rust control (Hall et al. 2011). [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/EC774-11.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC774-11.pdf)
- 2) Control volunteer wheat and grassy weeds in order to eliminate the green living bridge.
- 3) The use of fungicides is recommended for stripe rust control (Ruden and Osborne 2011). [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/FS917.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/FS917.pdf)
- 4) Fungicides effective for wheat leaf rust should be effective for stripe rust control.

### **Stagonospora (Septoria) leaf blotch**

*Symptoms:* Infected leaves develop dark tan, linear to irregular-shaped lesions (Fig. 23.8). Dark brown fruiting bodies called pycnidia develop later on the lesions. Lesions will often develop a yellow halo, but are distinguishable from tan spot by the presence of pycnidia. On mature leaves, the lesions may coalesce forming larger brownish dead areas (Fig. 23.9). The glumes may be infected and produce purple brown blotches with ash grey areas (Fig. 23.10). This phase of the disease is usually called glume blotch.

*Causal pathogen:* Stagonospora leaf blotch is caused by the fungus *Stagonospora nodorum* which was formerly known as *Septoria nodorum*.





**Figure 23.8. Stagonospora leaf blotch on wheat.**  
(Image: Paul Bachi, University of Kentucky Research and Education Center, Bugwood.org)



**Figure 23.9. Some spots caused by Stagonospora infection may later coalesce and produce larger brown dead areas on the leaves.**  
(Image: Paul Bachi, University of Kentucky Research and Education Center, Bugwood.org)



**Figure 23.10. Wheat glumes infected by *Stagonospora nodorum*.**  
(Image: Erik Stromberg, Virginia Polytechnic Institute and State University, Bugwood.org)

*Life cycle:* The pathogen causing Stagonospora leaf blotch survives the winter as mycelia or fruiting bodies (either pycnidia or pseudothecia) on crop residues. In the spring, the fungal fruiting bodies produce spores that are carried by wind and rain-splashed onto plant tissues. After infecting the tissues, the fungal pathogen produces conidia that can infect adjacent plants (Fig. 23.11). Temperatures ranging between 68–80.6°F (20–27°C) together with 6–16 hours of high humidity are favorable for the pathogen's development. The conidia produced on leaves may be splashed to heads, which lead to head infection especially during wet summers.



**Figure 23.11. Conidia produced on the infected leaf tissues.**

(Image: Paul Bachi, University of Kentucky Research and Education Center, Bugwood.org)

#### *Management:*

- 1) Plant varieties with moderate resistance.
- 2) Similar to tan spot and powdery mildew, the pathogen causing *Stagonospora* leaf blotch survives the winter on crop residues. Thus, burying the inoculum into the soil by tillage decreases the risk of the disease.
- 3) Continuous wheat crop rotations allows for the buildup of inoculum in a given field. A three-year crop rotation with two years of non-cereal crops is recommended.

### ***Fusarium head blight or scab***

*Symptoms:* In infected plants, spikelets on the whole or parts of the head appear bleached (Fig. 23.12). Pink or orange-red spore masses are sometimes visible at the base of the glumes, especially during long periods of high humidity. Purple-black perithecia, fruiting bodies of the pathogen, can sometimes be seen on older scab infections. Scab infection is favored by warm, wet weather for two weeks before flowering and continuing through the flowering period.

*Causal pathogen:* The fungus, *Fusarium graminearum*, causes head blight. Apart from wheat, this fungal pathogen also infects sorghum, oats, barley and corn. The pathogen causes stalk rot on sorghum and ear rot on corn.

*Life cycle:* *Fusarium graminearum* overwinters on small grains and corn residues in the field. In the spring and summer, the fungi can continue to multiply on the above-ground residues. Spores produced are rain-splashed or carried by wind on to the head. Spores can also be blown from long distant sources. The spores landing on wheat heads may germinate and grow through the anthers into the glumes. Critical time of infection occurs between the start of flowering and the hard dough of kernel development.

Prolonged periods of high humidity (2–3 days) coupled with temperatures ranging between 75° and 85°F (23.9–29.4°C) are favorable for disease development. Infection may also occur under lower temperatures, if the period of high humidity exceeds three days. Scabby wheat may have elevated levels of the mycotoxin, deoxynivalenol (DON). This toxin may have negative impact on livestock performance (Box 23.1, at end of chapter).

#### Management:

- 1) Wheat varieties differ in their response toward *Fusarium graminearum*. No varieties are immune, but some are moderately resistant. Choosing varieties with some levels of resistance should be the first management option in areas with scab history.
- 2) Since the pathogen survives on crop residues on the soil surface, tillage should reduce the risk of scab inoculum carrying over from the previous year. Crop rotation with broad leaf crops is also efficient in reducing the inoculum buildup in a given field. The highest risk of scab infection occurs in continuous wheat cropping or in wheat planted on previous year's corn residue.
- 3) Seed treatment reduces the incidence of wheat scab due to usage of infected seeds (Ruden and Osborne 2011); however, seed treatment does not reduce the risk of subsequent scab infection. [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/FS949.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/FS949.pdf)
- 4) Foliar fungicide application at flowering (when the anthers are still yellow) can be effective in reducing wheat scab and DON. Use the wheat scab risk assessment tool to make a fungicide application decision. [http://www.wheatscab.psu.edu/riskTool\\_2011.html](http://www.wheatscab.psu.edu/riskTool_2011.html)



**Figure 23.12. Bleached spikelets characteristic of *Fusarium* head blight or scab.**

(Image: Mary Burrows, Montana State University, Bugwood.org)

## ROOT ROT DISEASES

There are a number of pathogens that can cause root rot problems in South Dakota wheat. These include Common root rot complex, *Fusarium* foot rot, and Take-all. More than one root rot pathogen is often found infecting the same plant. Stressed plants are more susceptible to root rot diseases.

*Common root rot symptoms:* Infections may take place at any plant growth stage. Seedlings will often display dark brown lesions on the roots, subcrown internodes, crowns, and lower leaf sheaths (Fig. 23.13). Chocolate-brown leaf spots are often found on lower leaves. Surviving seedlings may be wilted, stunted, and chlorotic. Sterile white heads may result from premature death of the plant when infection is severe. Common root rot is favored by dry, droughty conditions.

*Fusarium foot rot symptoms:* Roots are often brown, the subcrown internode is discolored, and a chocolate brown or reddish brown lesion often extends up the plant stem (Fig. 23.14). A pink, cottony fungal growth may sometimes be found in the interior of the lower stem when it is split open. *Fusarium* foot rot also produces sterile white heads and premature plant death. The severity of this disease is also worsened by prolonged drought and dry conditions.





**Figure 23.13. Chocolate-brown lesions of common root rot located on roots and lower stems.**  
(Image: Mary Burrows, Montana State University, Bugwood.org)

*Take-all symptoms:* Roots and crowns appear as a shiny black color (Fig.23.15 and Fig. 23.16). White heads are often observed. In contrast to Common root rot and Fusarium foot rot, Take-all is favored by poorly drained wet soils. Take-all also tends to be more severe near the field edge where it uses grassy weeds for alternate hosts.



**Figure 23.14. Brown discoloration of crown and roots observed on Fusarium infected wheat.**  
(Image: Ernesto Moya, Bugwood.org)

*Causal pathogens:* *Bipolaris sorokiniana* causes common root rot complex of wheat. This fungus can also infect most small grains and numerous grasses. Take-all is caused by *Gaumanomyces graminis* var. *tritici*. Fusarium root rot (dryland root rot) is caused by several different species of *Fusarium* spp.



**Figure 23.15. Shiny black discoloration on roots and crowns of wheat infected with Take-all.**  
(Image: Mary Ann Hansen, Virginia Polytechnic Institute and State University, Bugwood.org)



**Figure 23.16. Take-all root rot on wheat.**  
(Image: Mary Burrows, Montana State University, Bugwood.org)

*Life cycle:* These diseases are soil borne. The fungus spores persist in soil on old stubble and root debris.

*Management:*

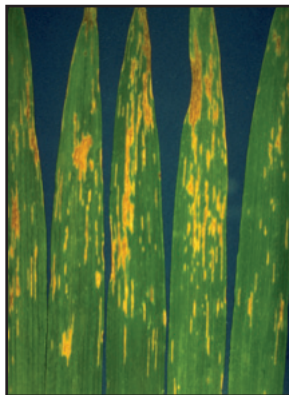
- 1) Crop rotation with a broadleaf crop.
- 2) Plant varieties with moderate resistance.
- 3) Use fungicide treated seed.

## BACTERIAL DISEASE

The main bacterial disease that attacks South Dakota wheat is black chaff, or bacterial leaf streak. Just a reminder, **foliar fungicides do not offer protection against bacterial diseases.**

### ***Black chaff/Bacterial leaf streak***

*Symptoms:* The disease earns its name, black chaff, from the darkened glumes of infected plants. This symptom is easily confused with glume blotch caused by glume infection of *Stagonospora nodorum*. Plants with black chaff/bacterial leaf streak, however, show a diagnostic sign of cream to yellow ooze (bacterial exudates) on the plant surface especially in humid weather. The ooze starts as viscous liquid. The bacterial ooze may appear as distinct droplets or a thin sheet of exudates. The bacterial ooze later dries and appears as shiny areas on the plant surface. Small water-soaked spots or streaks usually appear on infected leaves. The lesions may enlarge, usually yellowish in color and elongate in shape (Fig. 23.17). As they developed, the lesions become necrotic (Fig. 23.18).



**Figure 23.17. Yellowish elongate spots/streaks associated with black chaff/bacterial leaf streak on wheat.**  
(Image: E.A. Milus, University of Arkansas, Bugwood.org)



**Figure 23.18. Yellow streaks associated with bacterial leaf streak turn necrotic as they age.**

(Image: E.A. Milus, University of Arkansas, Bugwood.org)

*Causal pathogen:* Black chaff/bacterial leaf streak on wheat is caused by the bacterium *Xanthomonas campestris* pv. *translucens*.

*Life cycle:* The bacteria that causes bacterial leaf streak can be introduced via infected seeds, which are estimated to be the highest factor in bacterial leaf streak introduction into wheat fields with no history of the disease. *Xanthomonas campestris* pv. *translucens* can also survive as epiphytes on volunteer wheat due to its large host range that includes grassy weeds. Alternatively, the pathogenic bacteria can survive on crop debris in the field. However, bacterial survival decreases when the debris decomposes.

Inoculum in crop debris is splashed during rainfall onto healthy tissues. The bacteria enter the host plant through stomatal openings or wounds. Droplets of bacterial ooze during high humidity periods may act as inoculum for secondary infection. The disease can develop under a relatively wide range of temperature (59–86°F or between 15 and 30°C) and humidity levels. Infection is enhanced under frequent rainfall.

*Management:*

- 1) Usage of certified, pathogen-free seeds is the primary option to manage bacterial leaf streak.
- 2) Controlling volunteer cereal and grassy weeds around a wheat field reduces the disease pressure on the field.
- 3) There are currently no wheat varieties with high levels of resistance against bacterial leaf streak.
- 4) Susceptibility varies among wheat varieties and usage of highly susceptible varieties in fields with history of bacterial leaf streak should be avoided.

## VIRAL DISEASES

In South Dakota, the two main viral diseases that attack wheat are *Wheat streak mosaic virus* and *Barley yellow dwarf virus*. Depending upon the year and stage of growth, wheat streak can cause a 10 to 80% loss in yield, while barley yellow dwarf can cause a 10 to 40% yield reduction. Just to reiterate, **foliar fungicides are not effective and do not offer protection against viral diseases.**

### ***Wheat Streak Mosaic Virus (WSMV)***

**Symptoms:** The major symptoms of wheat streak mosaic are stunted plants with mottled and streaked leaves. Light green and dark green or yellow and green mosaics that coalesce into streaks are characteristic of this disease (Fig. 23.19).

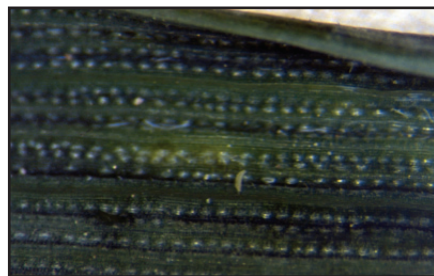
In severe reactions, streaks may become necrotic as disease progresses. Other symptoms include:

- 1) Spreading rather than erect growth (prostrating).
- 2) Delayed heading.
- 3) Reduced tillering.
- 4) Sterility or poor seed set.
- 5) Poor grain fill.
- 6) Reduced yields.



**Figure 23.19. Yellow streaking and mottling symptoms associated with Wheat streak mosaic virus (WSMV) infection on Lyman wheat.**  
(Image: Marie A.C. Langham, South Dakota State University)

**Causal pathogen:** The pathogen causing this disease is *Wheat streak mosaic virus* (WSMV). WSMV is transmitted from plant to plant by the wind-blown wheat curl mite (*Aceria tosichella* Keifer) (Fig. 23.20). Both the mites and virus survive winters on seeded and volunteer winter wheat and perennial grasses.



**Figure 23.20. Wheat curl mite, the vector of Wheat streak mosaic virus.**  
(Image: Frank Peairs, Colorado State University, Bugwood.org)

**Life cycle:** Infection typically takes place in the fall, but disease expression is often not observed until the spring. Mites and virus survive the winter in the crown of winter wheat and other perennial grasses. Wheat streak mosaic can also infect oats, barley, corn, sorghum, millets, and many other grass species. Symptoms are often found first along the edge of a field or in patches near wheat volunteers. WSMV is the most important endemic (always here, but varies in amount) viral disease in South Dakota.



### Management:

- 1) Avoid early planted winter wheat. Winter wheat planting should be delayed until after mid to late September for optimum WSMV control.
- 2) Volunteer grasses should be controlled at least two weeks before planting a new crop.
- 3) Early planted spring wheat is at less risk (mite populations increase with warmer temperatures) than late-planted spring wheat.
- 4) Use wheat cultivars with the most tolerance/resistance available in your area.

### ***Barley yellow dwarf/Cereal yellow dwarf***

**Symptoms:** The symptoms and severity of the disease are dependent on the age of the wheat when infected. In drought situations, infected wheat seedlings grow to only  $\frac{1}{3}$  or  $\frac{1}{2}$  of their normal size; the leaves suffer from chlorosis, and the heads may not be completely filled. If infection occurs after tillering, stunting is minimal or not present. Depending on the anthocyanin level of the wheat variety, the infected leaves turn bright yellow or reddish purple color (Fig. 23.21). Symptomatic plants can either appear singly or in circular groups within the field (Fig. 23.22). Plants infected by BYDV/CYDV have stunted root growth and, consequently, the impact of BYDV/CYDV infection is exacerbated in drought years.

**Causal pathogen:** Viruses causing barley yellow dwarf/cereal yellow dwarf are *Barley yellow dwarf virus* (BYDV) and *Cereal yellow dwarf virus* (CYDV). There are several distinct strains of these viruses: BYDV-PAV, BYDV-MAV and CYDV-RPV. Each strain is optimally transmitted by distinct aphid species and their geographic distribution varies. In South Dakota, BYDV-PAV is the predominant species causing barley yellow dwarf.

Over 100 species in the grass family are affected by the disease, including many common grain crops such as barley, wheat, oats, sorghum, rye, triticale, corn, and rice and numerous wild grasses. The wide host range provides many potential hosts for the virus in the absence of cultivated commodities. Wild annuals, perennial grassy weeds, volunteer cereals and neighboring cultivated grain crops may act as alternative hosts for the virus.



**Figure 23.22. A cluster of stunted and yellowed wheat plants infected with BYDV/CYDV.** (Image: William M. Brown Jr., Bugwood.org)



**Figure 23.21. Yellowing with reddish purple leaves associated with BYDV/CYDV infection on wheat.** (Image: William M. Brown Jr., Bugwood.org)

**Life cycle:** BYDV and CYDV are transmitted exclusively by aphids. A number of aphid species can transmit these viruses from plant to plant; two of the most important are bird cherry-oat aphid and English grain aphid. The winged form of bird cherry-oat aphid has a pale to dark green abdomen. The non-winged form is broadly oval and olive to greenish black in color with brownish coloration on the rear end of the body.

Both forms of bird cherry-oat aphid have black tailpipes (cornicles) and dark cauda (tail). The non-winged form of English grain aphid is medium sized, broadly spindle shaped, yellowish green to dirty reddish brown in color, with black tailpipes and pale cauda. The winged form of English grain aphid is similar in color with distinct dark markings across the back. Bird cherry-oat aphid is known to migrate in early fall while English grain aphid usually migrates in spring or summer.

The aphid vectors overwinter in the southern parts of the country and migrate northward in summer and early fall. Migration seems to be encouraged by cool (50° to 68° F or between 10° and 20° C) humid weather. Migrating aphids may introduce the virus or transmit the virus from infected perennial weeds to wheat. Infected wheat acts as inoculum source for viral spread in the field.

#### *Management:*

- 1) Planting date management is important in managing the yellow dwarves. Planting winter wheat after the migration season of bird cherry-oat aphid may reduce the risk of early BYDV/CYDV infection.
- 2) Even though highly resistant varieties are not available, wheat varieties vary in their response to BYDV/CYDV infection. Usage of varieties with low susceptibility against BYDV/CYDV is recommended.
- 3) Since perennial grassy weeds and volunteer wheat can act as virus reservoir for fall and spring infection, destruction of these plants around a wheat field will reduce the risk of BYDV/CYDV infection.
- 4) Fungicide has no effect on virus infection and development inside the wheat plant.
- 5) Insecticide seed treatment or foliar insecticide application can decrease aphid population and activity on wheat, thus reducing the spread of the disease within a field. However, usage of these chemical options is only economically feasible in years with high BYDV/CYDV severity. Since it is difficult to forecast the risk of BYDV/CYDV infection, it is similarly difficult to predict whether seed treatment or foliar insecticide will be profitable in a given year.

#### **Box 23.1. Mycotoxin**

Mycotoxin concentration can limit end-use or reduce profits due to dockage or rejection at the point of sale. In the case of wheat, *Fusarium* spp. produces the mycotoxin, deoxynivalenol (DON), otherwise known as vomitoxin. FDA animal feed guidelines are shown as follows:

1. Cattle and chickens – 10 ppm not to exceed 50% of the diet.
2. Swine – 5 ppm not to exceed 20% of the diet.
3. All other animals – 5 ppm not to exceed 40% of the diet; can reduce weight gain and feed refusal at lower levels.
4. Human consumption – FDA recommendation < 1 ppm.

#### Additional information and references

Bockus, W.W. 2010. *Compendium of Wheat Diseases and Pests*. Third edition. The American Phytopathological Society, St. Paul, MN.

DeWolf, E., J.P. Shroyer, and B. Olson. 2011. *Wheat Disease Identification*. USDA-NIFA Extension Integrated Pest Management Program 2009-41533-05331 Publication. Redistributed through SDSU Extension. Available at <http://www.ksre.ksu.edu/library/plant2/mf2994.pdf>

Draper, M.A. and D. Deneke. 2010. *Recognizing and managing common crop diseases in South Dakota*. ExEx8005. South Dakota State University, SDSU Extension, Brookings, SD. Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/ExEx8005.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/ExEx8005.pdf)

Draper, M.A., C. Stymiest, and Y. Jin. 2000. *Common root and crown rot diseases of wheat in South Dakota*. ExEx8138. South Dakota State University, SDSU Extension, Brookings, SD. Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/ExEx8138.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/ExEx8138.pdf)

Hall, R.G., J. Rickertswan, K.K. Kirby, J. Hall, and B. Swan. 2011. *Small grains: 2010 South Dakota test results, variety traits, and yield averages*. EC774. South Dakota State University. Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/EC774-11.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC774-11.pdf)

Osborne, L.E., and J. Stein. 2009. *South Dakota wheat fungicide recommendations*. FS952. South Dakota State University, SDSU Extension, Brookings, SD. Available at <http://www.sdwheat2.org/files/Fungicide09S952.pdf>

Ruden, K., and L.E. Osborne. 2011. *Managing crop diseases with fungicides*. FS917. South Dakota State University, SDSU Extension, Brookings, SD. Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/FS917.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/FS917.pdf)

Ruden, K., and L.E. Osborne. 2011. *Managing crop diseases with seed treatments*. FS949. South Dakota State University, SDSU Extension, Brookings, SD. Available at [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/FS949.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/FS949.pdf)

#### Acknowledgements

The authors would like to thank Dr. Marie A.C. Langham for her help with editing and reviewing this chapter. Support was also provided by SDSU Extension.

---

Strunk, C.L., and B. Hadi. 2012. *Wheat diseases in South Dakota*. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.



**Table 23.1. Wheat disease scouting calendar for South Dakota.** This chart is adapted from the 2011 field crop pest calendar published by SDSU Extension.

Disease	Wheat stage							
	Fall	Winter	Emergence	Tillering	Jointing	Boot	Heading & Flowering	Grain fill
Tan spot								
Winter wheat								
Spring wheat								
Powdery mildew								
Stagonospora leaf blotch								
Glume blotch (Stagonospora)								
Leaf rust								
Stripe rust								
Stem rust								
Fusarium head blight / wheat scab								
Root rot diseases								
Black chaff / bacterial leaf streak								
BYDV								
Winter wheat								
Spring wheat								
WSMV								
Winter wheat								
Spring wheat								

- Effective in-season management options for diseases such as black chaff/bacterial leaf streak, root rot complex, WSMV or BYDV are either not available or are not consistently profitable. Any decision regarding disease management should be taken before planting. Examples of management options for these diseases typically include planting date management, selection of resistant varieties, usage of disease-free seed, crop rotation and, in the case of root rot complex, fungicide seed treatment. Details on each option are discussed under individual disease sections.
- At tillering (Chapter 3), scout for early season leaf diseases (tan spot, powdery mildew, stagonospora leaf blotch and stripe rust).
  - Light infection is normal and tolerable.
  - Economic treatment using early rates of fungicides is warranted only when all of the following conditions are met.
    - The field contains heavy stubble from previous wheat crop.
    - The variety seeded is susceptible or moderately susceptible.
    - There has been abundant rainfall.

Early application of fungicides is typically conducted at half the recommended rates. This increases the risk of fungicide resistance development among the field pathogen population. To prevent fungicide resistance development, early applications of strobilurin fungicides (e.g., Headline®, Quadris®, etc.) should not be followed by flag leaf applications with products with the same class of active ingredients (Table 23.1).

3. At flag leaf emergence, check for leaf spot/blotch and rust diseases.
  - a. Check flag leaf and two leaves below for signs of leaf spots/blotch, leaf and stripe rust.
  - b. If rust or heavy leaf spots (10% leaf area on 1<sup>st</sup> leaf below flag or 20% leaf area on 2<sup>nd</sup> leaf below flag) are present, consider fungicide application.

*Note that varieties resistant to leaf and/or stripe rusts only need protection for leaf spot/blotch.*

4. After head emergence, check for flowering stage. Stage of anther development is important in the timing of some fungicide applications and for checking if flower development was harmed by unfavorable weather conditions.
  - a. Monitor the weather forecast at this time. Wet soils, heavy dew, frequent rainfall, and warm temperatures favor scab infection.
  - b. If favorable weather conditions prevail and susceptible varieties are planted, consider scheduling fungicide application (Table 23.1) near or at the peak of flowering (when the anthers are still yellow).
5. Three weeks after flowering, check for scab development.
  - a. Greater than 10% disease may translate into elevated toxin levels in grain.
  - b. Explore insurance and/or marketing options, may require pre-harvest testing.

**Table 23.2 Efficacy of fungicides for wheat disease control based on appropriate application timing.<sup>1</sup>**

Fungicide		Powdery mildew	Tan spot/ Stagon- ospora leaf blotch	Leaf rust	Stripe rust	Stem rust	Fusarium head scab	Harvest restriction (days before harvest)
Active ingredient (Product example) <sup>2</sup>	Rate/ A (fl. oz)	Applied at flag leaf (Feekes 8-9)				Applied between emergence and flowering	Applied at flowering (Feekes 10.51)	
Class: Strobilurin – high risk fungicide resistance								
Azoxystrobin Quadris 2.08 SC	6.2 – 10.8	F	VG – E	E	E	VG	NL	45 days
Fluoxastrobin Evito 480 SC	2.0 – 4.0	G	--	VG	--	--	NL	40 days
Pyraclostrobin Headline SC	6.0 – 9.0	G	VG – E	E	E	G	NL	Feekes 10.5
Class: Triazole – medium risk of fungicide resistance								
Cyproconazole Alto 100 SL	3.0 – 5.5	--	--	--	--	--	--	30 days
Metconazole Caramba 0.75 SL	10.0 – 17.0	VG	VG	E	E	E	G	30 days
Propiconazole Tilt 3.6 EC	4.0	VG	VG	VG	VG	VG	P	Feekes 10.5
Prothioconazole Proline 480 SC	5.0 – 5.7	--	VG	VG	--	VG	G	30 days
Tebuconazole Folicur 3.6 F	4.0	G	VG	E	E	E	F	30 days
Prothioconazole + Tebuconazole Prosaro	6.5 – 8.2	G	VG	E	E	E	G	30 days
Class: Triazole + Strobilurin								
Metconazole + Pyraclostrobin TwinLine 1.75 EC	7.0 – 9.0	G	VG – E	E	E	VG	NL	Feekes 10.5
Propiconazole 11.7% + Azoxystrobin 7.0% Quilt 200 SC	14.0	VG	VG	E	E	VG	NL	Feekes 10.5
Propiconazole 11.7% + Azoxystrobin 13.5% Quilt Xcel 2.2 SE	14.0	--	VG <sup>a</sup>	VG	--	--	NL	Feekes 10.5
Propiconazole 11.4% + Trifloxystrobin 11.4% Stratego 250 EC	10.0	G	VG	VG	VG	VG	NL	35 days
Propiconazole 22.6% + Trifloxystrobin 22.6% Absolute 500 SC	5.0	G	--	E	--	--	NL	35 days

<sup>1</sup>This table is based on the work of North Central Regional Committee on Management of Small Grain Diseases (last update on April 2011), and is provided only as a guideline. Pesticide applicators are responsible to read and follow all current label directions. No endorsement is intended for any of the listed products. We assume no liability resulting from the use of these products.

<sup>2</sup>Other products containing the same active ingredients may also be labeled in some states.

**Efficacy categories:**

NL = Not labeled and Not Recommended      P = Poor  
 F = Fair      G = Good  
 VG = Very Good      E = Excellent  
 -- = Insufficient data to make statement about the efficacy of this product.



## CHAPTER TWENTY-FOUR

# Weed Identification

Sharon A. Clay ([Sharon.Clay@sdstate.edu](mailto:Sharon.Clay@sdstate.edu))

This chapter is the first of three that discusses weed identification (Chapter 24), targeted weed control strategies (Chapter 25), and herbicide injury symptoms (Chapter 26). The objective of this chapter is to provide guidance for identifying weeds found in South Dakota wheat fields.

### **Introduction**

Without proper identification, weed control practices and herbicide recommendations may not provide expected results. Small (young) weeds, which are difficult to identify, are controlled more easily with less herbicide than larger, more well-established weeds. Control strategies should consider the weed species, chemicals, and crop rotations. For example, winter wheat is often more competitive with spring-emerging weeds than spring wheat. If emerged weeds are present at planting for either winter or spring wheat, they should be controlled as soon as possible.

Weeds can have multiple impacts on wheat that include reduced yields and diminished quality. If immature weeds are present at harvest, post-harvest control measures should be undertaken to insure that additional weed seeds are not added to the soil. Perennial weed control should be undertaken first, in early summer prior to flowering, and, then again, in fall, after the first light frost to help control growth from perennating organs. Weeds observed in South Dakota fields can be classified as grasses or broadleaf plants.

Grass Weeds	Broadleaf Weeds
wild oat	wild buckwheat
longspine sandbur	horseweed
downy brome	common sunflower
Japanese brome	common cocklebur
cheat	Russian thistle
jointed goatgrass	redroot pigweed
barnyardgrass	common waterhemp
wild proso millet	common lambsquarters
yellow foxtail	kochia
green foxtail	Canada thistle
large crabgrass	field bindweed
witchgrass	wild mustard
switchgrass	field pennycress
annual and perennial ryegrass	prickly lettuce
volunteer rye	flixweed
	tansy mustard

*Images and description of selected weeds are provided below.*

## Grass Weeds

### Wild oat (*Avena fatua*)

**Time of emergence:** Wild oat typically emerges early; before or just after planting depending on soil temperature and moisture conditions.

**Life cycle and reproduction:** Annual, reproducing from seed.

**Distinguishing characteristics:** Large membraneous ligule, leaf blade margins with long hairs, leaves twist counter-clockwise, bunch grass. Typically occurs in localized areas.

**Yield loss potential:** One wild oat per ft<sup>2</sup> may result in yield losses up to 10%.

**Herbicide resistance:** South Dakota biotypes that are resistant to ACCase inhibitors such as fenoxaprop have been identified. Across the United States, biotypes resistant to dinitroaniline (e.g., Treflan®); imidazolinone and sulfonylurea (ALS inhibitors); and thiocarbamates (e.g., EPTC) have been identified.

Wild oat ligule and plant descriptions available online at [www.ipm.ucdavis.edu/PMG/WEEDS/wild\\_oat.html](http://www.ipm.ucdavis.edu/PMG/WEEDS/wild_oat.html)



**Figure 24.1. Mature wild oat.**  
(Photo courtesy of Mike Moechnig, SDSU)

### Longspine sandbur (*Cenchrus longispinus*)

**Time of emergence:** Longspine sandbur is a non-native, warm-season grass emerging after planting.

**Life cycle and reproduction:** Annual, reproduces from seed.

**Distinguishing characteristics:** Sandbur has flattened stems with hairs, leaves may be rough to the touch. The plant has a short fringed hairy ligule. Seeds are enclosed in sharp, spiny, hairy burs that give the plant its name. Generally found in sandy soils, although it may also be found in clay loam soils.

**Yield loss potential:** Yield loss is often low; however, the plant is a nuisance plant due to sharp burs.

**Herbicide resistance:** None has been reported.



**Figure 24.2. Longspine sandbur.**  
(Photos courtesy of Mike Moechnig, SDSU)

### Downy brome (*Bromus tectorum*) (cheatgrass)

**Time of emergence:** Downy brome typically emerges after winter wheat seeding in the fall and occasionally in early spring.

**Life cycle and reproduction:** It is an annual that reproduces from seed.

**Distinguishing characteristics:** Leaves and sheaths are softly hairy. Ligule is rounded and may be toothed. It has long awns on the seed and a drooping panicle with many branches. The plant dries early in the summer. It is more common in crop land than the other brome species.

**Yield loss potential:** One plant per ft<sup>2</sup> can reduce yields 30%, while heavy infestations can reduce yields up to 80%.

**Herbicide resistance:** Biotypes in the U.S. are resistant to lipid synthesis (ACCase inhibitors) or ALS inhibitors (imidazolinone and sulfonylurea). Around the world, biotypes are resistant to urea-type herbicides and photosystem II inhibitors.

Additional information about this weed is available at <http://msuextension.org/publications/AgandNaturalResources/MT200811AG.pdf>



**Figure 24.3. Downy brome** (Photos courtesy of Mike Moechnig, SDSU)



**Japanese brome (*Bromus japonicus*)**

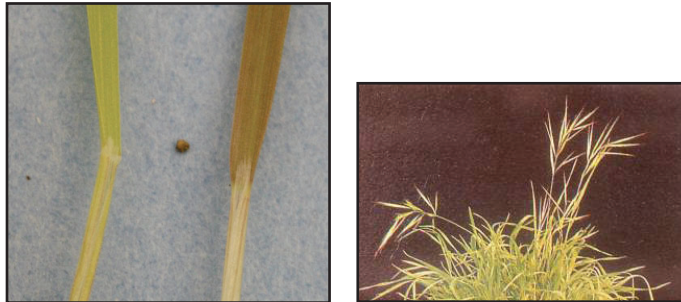
**Time of emergence:** Winter annual, germinates late fall, remains vegetative until spring.

**Life cycle and reproduction:** Annual, reproducing from seed.

**Distinguishing characteristics:** Leaf sheath is hairy while the blade is hairless. It has short awns on the seed and a more upright seed head than downy brome. Although Japanese brome may be found in crop fields, it is often more common in rangeland.

**Yield loss potential:** No specific information is available.

**Herbicide resistance:** U.S. biotypes are resistant to herbicides with ALS-inhibitor mode of action (imidazolizone and sulfonylurea).



**Figure 24.4. Mature Japanese brome.**

(Photo courtesy of Pacific Northwest Weed Management Handbook and <http://mining.state.co.us/pdfFiles/DownyBromeandJapanesebrometechnicalbulletinGBeckCSUDec092.pdf>)

**Cheat (*Bromus secalinis*)**

**Time of emergence:** Cheat typically emerges in the fall or early spring; before or just after planting depending on soil temperature and moisture conditions. Cheat initiates its reproductive growth in mid-March, flowers and sets seed in May, and finally matures in early June.

**Life cycle and reproduction:** Annual, reproducing from seed.

**Distinguishing characteristics:** Ligule is rounded and may be toothed. It has short awns on the seed and typically occurs in localized areas, prefers dry soil conditions. Although downy brome and Japanese brome are often referred to as “cheatgrass,” true cheat is generally not common in South Dakota.

**Yield loss potential:** 25 plants per ft<sup>2</sup> may result in 30 to 40% yield loss. Dockage may occur when infested wheat is marketed.

**Herbicide resistance:** U.S. biotypes are resistant to herbicides with ALS-inhibitor mode of action (imidazolizone and sulfonylurea).



**Figure 24.5. Ligule.**

(Photo courtesy of <http://wiki.bugwood.org/HPIPM:Cheat>) and **Mature Cheat.** (Photo courtesy of Pacific Northwest Weed Management Handbook)



### Jointed goatgrass (*Aegilops cylindrica*)

**Time of emergence:** Jointed goatgrass typically emerges in the fall or early spring.

**Life cycle and reproduction:** Annual, reproducing from seed.

**Distinguishing characteristics:** Jointed goatgrass has long visible hairs along the blade and leaf sheath and unlike wheat, has reduced auricles. At heading, the inflorescence of jointed goatgrass is a cylindrical spike that has many joints. Each joint can contain up to three seeds. Spikelets that are harvested with wheat look like straw contamination; however, wheat straw is hollow and the goatgrass spikelet will be solid.

**Yield loss potential:** 2 plants ft<sup>2</sup> has been shown to reduce yields up to 30%, if winter wheat and jointed goatgrass emerge at the same time. In addition, infested wheat grain delivered to an elevator is discounted for dockage.

**Herbicide resistance:** No resistant biotypes have been reported. <http://www.jointedgoatgrass.org/>



**Figure 24.6. Wheat Jointed goatgrass and Jointed goatgrass with wheat seed.**  
(Photos courtesy of Steve Dewey, Utah State University, Bugwood.org and Phil Westra, Colorado State University, Bugwood.org)

### Barnyardgrass (*Echinochloa crus-galli*)

**Time of emergence:** Barnyardgrass is a warm-season grass emerging midseason after spring wheat planting.

**Life cycle and reproduction:** Annual, reproduces by seed.

**Distinguishing characteristics:** This grass has flattened, smooth, and branched stems without an auricle or ligule. This grass has broad leaves and typically is reddish or purple at the base of the plant. Barnyardgrass size can vary from 2 inches to over 4 feet tall. Larger plants are found around field edges or in areas with poor canopy cover. Found in wetter areas of the field.

**Yield loss potential:** Yield loss is often low.

**Herbicide resistance:** U.S. biotypes are resistant to photosynthetic inhibitors (e.g., atrazine), and the ACCase lipid synthesis inhibitors (e.g., sethoxydim).



**Figure 24.7. Barnyardgrass.** (Photo courtesy of Mike Moechnig, SDSU)

### Wild proso millet (*Panicum miliaceum*)

**Time of emergence:** Wild proso millet is a warm-season grass that typically emerges late in the season, after spring wheat emergence.

**Life cycle and reproduction:** Annual reproducing by seed.

**Distinguishing characteristics:** This warm-season grass has a round stem with membranous ligule tipped with a fringe of hair. Seedlings look like corn but are hairy. Leaf blades are flat. Hairs may or may not be on the blade and sheath, but hairs are present at nodes. This grass can grow up to 6 ft tall. Seeds large, shiny, and white, green striped, olive brown, or black and often remain on the root of seedlings, which helps in identification. Nonblack seeds in soil are usually not viable after two seasons; black seeds have been reported to remain viable for up to 4 years. It tolerates sandy, dry soils and high temperatures.

**Yield loss potential:** Yield loss is moderate to high.

**Herbicide resistance:** None noted at this time.



**Figure 24.8. Wild Proso Millet.** (Photos courtesy of Steve Dewey, Utah State University, Bugwood.org)

### Yellow foxtail (*Setaria pumila* syn. *S. glauca*) and Green foxtail (*S. viridis*)

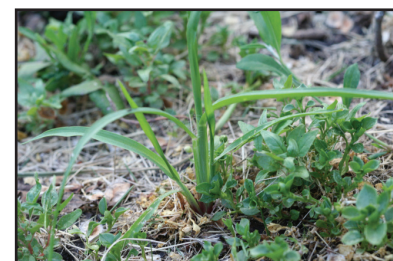
**Time of emergence:** Yellow and green foxtails emerge toward the end of spring wheat planting.

**Life cycle and reproduction:** Annuals reproducing by seed.

**Distinguishing characteristics:** Yellow and green foxtails infest most eastern South Dakota fields. Yellow foxtail has long yellow hairs near the ligule, a flattened stem, and large seeds. Green foxtail has no to few hairs on the leaf blade, a round stem, and small seeds.

**Yield loss potential:** In wheat, green foxtail populations of 38 per ft<sup>2</sup> can reduce yields from 14 to 62%.

**Herbicide resistance:** Yellow foxtail biotypes have been reported to be resistant to ALS and photosynthetic herbicides. Green foxtail biotypes have been reported to be resistant to dinitroaniline (trifluralin), ALS, lipid synthesis inhibitors (ACCase), and photosynthetic inhibitor herbicides.



**Figure 24.9. Yellow foxtail and green foxtail; young plant.** (Photos courtesy Mike Moechnig, SDSU)

### Large crabgrass (*Digitaria sanguinalis*)

**Time of emergence:** Large crabgrass is a warm season grass that emerges after spring wheat has emerged.

**Life cycle and reproduction:** Annual plant that reproduces by seed.

**Distinguishing characteristics:** Hairs are found everywhere on large crabgrass; it has a flattened stem, membranous ligule, and a seedhead that has finger-like spikes. This grass can grow from 6" to 2 ft tall.

**Yield loss potential:** Low even at high densities.

**Herbicide resistance:** Biotypes in Wisconsin have been reported to be resistance to the ACCase lipid synthesis inhibitor (e.g., sethoxydim) herbicides. In South Dakota, biotypes resistant to typical wheat herbicides have not been reported.



**Figure 24.10. Large crabgrass.** (Photos courtesy Mike Moechnig, SDSU)

### Witchgrass (*Panicum capillare*)

**Time of emergence:** Witchgrass is a warm-season grass that emerges after spring wheat emergence.

**Life cycle and reproduction:** Annual, reproducing by seed.

**Distinguishing characteristics:** Witchgrass has a flat stem with long soft hairs covering most of the plant. The ligule is a fringe of hair. Panicles are an open inflorescence, spreading, hairy, and large. When mature, the panicle can break off and tumble along the ground.

**Areas of infestation:** Grows well in sandy, droughty soil.

**Yield loss potential:** Low, even at high densities.

**Herbicide resistance:** A biotype resistant to photosynthetic type herbicides (e.g., atrazine) has been observed in Canada.



**Figure 24.11. Witchgrass.**

(Photos courtesy of Howard F. Schwartz, Colorado State University, Bugwood.org and Steve Dewey, Utah State University, Bugwood.org)



### Switchgrass (*Panicum virgatum*)

**Time of emergence:** Switchgrass is a warm-season grass that emerges after spring wheat has emerged.

**Life cycle and reproduction:** This perennial reproduces by rhizomes and seed. Vegetative stems are sometimes confused with witchgrass.

**Distinguishing characteristics:** There is a V-shaped patch of hair on the upper leaf surface near the stem. Plants can grow up to 6 ft tall. Switchgrass has been grown in CRP lands and is being examined as a biofuel crop, but escaped plants can be problematic.

**Areas of infestation:** Switchgrass grows well in sandy or droughty soil types.

**Yield loss potential:** Moderate.

**Herbicide resistance:** No resistance to typical wheat herbicides have been reported.



**Figure 24.12. Switchgrass.**  
(Photo courtesy of James H. Miller and Ted Bodner, Southern Weed Science Society, Bugwood.org)

### Annual (Italian) and perennial ryegrass (*Lolium multiflorum* and *L. perenne*)

**Time of emergence:** Annual ryegrass is a cool-season grass emerging in early spring before or at spring wheat planting.

**Life cycle and reproduction:** Annual ryegrass is a bunchtype grass that reproduces by seed only. Perennial ryegrass can reproduce by seed and rhizomes.

**Distinguishing characteristics:** Leaves are dark green. Annual ryegrass has long clasping auricles that wrap around the stem. Seeds of annual ryegrass have long awns. Perennial ryegrass has short nonclasping auricles and seeds are awnless.

**Areas of infestation:** Often grows and thrives in moist soils and can withstand temporary flooding better than cereals.

**Yield loss potential:** Populations exceeding 20 plants/ft<sup>2</sup> can reduce wheat yields from 20 to 50%. Some wheat varieties have been shown to reduce ryegrass growth due to chemical exudates (allelopathy) from roots or decaying leaf tissue.

**Herbicide resistance:** Biotypes of *Lolium multiflorum* are resistant to ACCase inhibitors such as diclofop (Hoelon<sup>®</sup>). Biotypes of *Lolium rigidum* have been reported to be resistant to glyphosate, ACCase inhibitors, and ALS (both sulfonylurea and imidazolinone type) inhibitors.

**Other species:** Rigid ryegrass (*Lolium rigidum*) and others. Identification information can be found online at University of Arkansas website Ryegrass Identification Keys: [http://www.uaex.edu/Other\\_Areas/publications/PDF/FSA-2149.pdf](http://www.uaex.edu/Other_Areas/publications/PDF/FSA-2149.pdf)



**Figure 24.13. Italian (or annual) ryegrass spike.**  
(Photo courtesy of Barry Rice, sarracenia.com, Bugwood.org)

### **Volunteer (or feral) Rye (*Secale cereale*)**

**Time of emergence:** Volunteer rye is a winter annual that emerges in the late fall or early spring.

**Life cycle and reproduction:** Annual plant that reproduces by seed.

**Distinguishing characteristics:** Its bluish green leaves are coarser than wheat and it has a short membranous ligule. Auricles are narrow and wither away as the season progresses compared to wheat auricles, which are present throughout the season. The seed head of rye will nod, whereas wheat remains upright. Images of seedling wheat compared with seedling rye can be found at <http://new.dpi.vic.gov.au/agriculture/grain-crops/crop-production/identifying-cereal-seedlings>

**Areas of infestation:** Often grown as a cover crop or in pastures, planted rye can escape and cause problems as it has dormant seed that can survive many disturbances.

**Yield loss potential:** Often interferes with winter wheat production. The presence of rye seeds in wheat grain often results in dockage, grain grade reduction, and quality losses. In Colorado, 5 plts/ft<sup>2</sup> resulted in 14% wheat yield loss, and, in Oregon, if left until harvest, a 69% yield reduction was reported with 18 plts/ft<sup>2</sup>.

**Herbicide resistance:** Not truly herbicide resistant; however, controlling volunteer rye in wheat can be problematic. Online information about managing volunteer rye infestations in winter wheat can be found at: <http://www.wintercereals.us/Documents/Growing%20WW/Production%20Articles/Weeds/Rye%20Control%20in%20Winter%20Wheat.pdf>



**Figure 24.14. Feral rye in wheat.** (Photos courtesy of Drew Lyon, UNL)

## Broadleaf Weeds

### Wild buckwheat (*Polygonum convolvulus*)

**Time of emergence:** Wild buckwheat typically emerges before or at planting of spring wheat. Later summer flushes may occur depending on soil temperature and moisture conditions.

**Life cycle and reproduction:** Annual vining broadleaf that reproduces by seed.

**Distinguishing characteristics:** An ocrea (white to brown sheath) is located at the base of the leaf on the stem. This plant is often confused with the perennial field bindweed and is known as black bindweed in other regions. Unlike field bindweed, wild buckwheat has triangular seeds, an ocrea, very small inconspicuous flowers, pointed leaf tips, and a fibrous root structure. Wet areas of fields are more likely to have infestations.

**Yield loss potential:** Yield losses can be as high as 30%. Low densities may not reduce yield; however, the vines twining up wheat plants may become tangled in harvest equipment. If mixed with wheat, the high water content of wild buckwheat seeds may cause spoilage in stored grain.

**Herbicide resistance:** No resistance reported, but difficult to control with glyphosate or 2,4-D.



Figure 24.15. Wild buckwheat. (Photos courtesy of Mike Moechnig, SDSU)

### Horseweed or marestail (*Conyza canadensis*)

**Time of emergence:** Horseweed may emerge in fall in winter wheat, overwinter as a rosette, and bolt in the spring or emerge in the spring at or before spring wheat planting.

**Life cycle and reproduction:** This winter or summer annual reproduces from seed.

**Distinguishing characteristics:** The plant has numerous linear, hairy (although some plants have few or no hairs) leaves crowded on the stem. It is tolerant of drought conditions. The flowers are very small and are generally white.

**Yield loss potential:** Historically, this weed has seldom been dense enough to warrant control and is generally not highly competitive with wheat. However, at high densities yield losses of >80% have been reported in soybean.

**Herbicide resistance:** There are biotypes resistant to photosynthetic inhibitors (atrazine), glyphosate, ALS inhibitors, and paraquat. Rotating herbicides or other control methods is necessary to minimize selection of herbicide resistant biotypes.



Figure 24.16. Horseweed. (Photos courtesy of Mike Moechnig, SDSU)



### Common sunflower (*Helianthus annuus*)

**Time of emergence:** Common sunflower emerges at or just after spring wheat planting.

**Life cycle and reproduction:** Annual, reproducing by seed.

**Distinguishing characteristics:** Cotyledons are oval with toothed margins on alternating leaves. Stems become multi-branched, covered with stiff hairs as the plant matures and has characteristic yellow flowers. Infestations typically occur in drier soils.

**Yield loss potential:** Highly competitive with up to 70% yield reductions are observed at moderate density.

**Herbicide resistance:** Biotypes resistant to ALS-inhibitor herbicides have been reported.



Figure 24.17. Common sunflower. (Photos courtesy of Mike Moechnig, SDSU)

### Common cocklebur (*Xanthium strumarium*)

**Time of emergence:** Common cocklebur typically emerges after spring wheat planting.

**Life cycle and reproduction:** Annual plant that reproduces by seed.

**Distinguishing characteristics:** Cotyledons of the seedling are linear, thick, and shiny green. Leaves are alternate and large with wavy margins. Seeds are in burs that stick to animal coats. This plant grows well in wet areas.

**Yield loss potential:** Highly competitive, causing up to 70% yield reductions at high density.

**Herbicide resistance:** Biotypes resistant to ALS-inhibitor herbicides have been reported in some Midwestern states.



Figure 24.18. Common cocklebur. (Photos courtesy of Mike Moechnig, SDSU)

### Russian thistle (*Salsola iberica*)

**Time of emergence:** Russian thistle emerges at or before spring wheat planting.

**Life cycle and reproduction:** Annual plant that reproduces by seed.

**Distinguishing characteristics:** Seedlings resemble small pine trees with threadlike leaves.

Older plants become spine-like with the leaf surface from smooth to hairy with non-showy flowers. The entire plant breaks off at the base and disperses seed as it tumbles in the wind.

This drought- and salt-tolerant plant can be found in many areas.

**Yield loss potential:** Up to 50% yield reductions have been reported depending on density and time of emergence. If Russian thistle comes up even one week after the crop, wheat losses may not be measurable.

**Herbicide resistance:** Biotypes resistant to ALS-inhibitor herbicides have been observed.



**Figure 24.19. Russian thistle.** (Photos courtesy of Mike Moechnig, SDSU)

### Redroot pigweed (*Amaranthus retroflexus*)

**Time of emergence:** Redroot pigweed typically emerges at or during spring wheat planting.

**Life cycle and reproduction:** Annual plant that reproduces by seed.

**Distinguishing characteristics:** Cotyledons are thin and linear. Leaves are lance-like with alternate arrangement. The lower surface is hairy. Stems are stout and the lower portion is reddish (hence the name redroot). Seeds are black, shiny, and numerous with a large plant producing over 800,000 seeds. Plants may hybridize with other *Amaranthus* species (e.g., Palmer amaranth, common waterhemp, prostrate pigweed). This plant typically is found in disturbed areas usually with high fertility.

**Yield loss potential:** Up to 55% yield reductions reported depending on density.

**Herbicide resistance:** Biotypes resistant to triazine and ALS-inhibitor herbicides have been reported.



**Figure 24.20. Redroot pigweed.** (Photos courtesy of Mike Moechnig, SDSU)

### Common waterhemp (*Amaranthus rudis*)

**Time of emergence:** Common waterhemp typically emerges late in the season after spring wheat emergence.

**Life cycle and reproduction:** Annual plant that reproduces by seed.

**Distinguishing characteristics:** The first true leaves of seedlings are more lance-like than the oval leaves seen on redroot pigweed. Leaf surfaces are not hairy. This plant has male and female plants. The inflorescence of the female plant is more highly branched than the inflorescence of the redroot pigweed. The female plant has been reported to produce over one million shiny black seeds. Found in disturbed areas with high fertility.

**Yield loss potential:** Up to 55% yield reductions reported depending on density.

**Herbicide resistance:** Biotypes have been reported to be resistant to ALS-inhibitors, triazine, glyphosate, and PPO type herbicides. Biotypes with multiple resistance (e.g., resistant to several different modes-of-action) also have been reported.



**Figure 24.21. Common waterhemp.** (Photos courtesy of Mike Moechnig, SDSU)

### Common lambsquarters (*Chenopodium album*)

**Time of emergence:** Common lambsquarters typically emerges at or before spring wheat planting.

**Life cycle and reproduction:** Annual plant that reproduces by seed.

**Distinguishing characteristics:** Emerging plants are very small. Leaves are opposite and are covered with a mealy powder, especially on the underside. The stems are erect, may have green or red stripes and can grow to almost 6 ft tall under certain conditions. The flowers are nonshowy and without petals.

**Yield loss potential:** Up to 30% yield reductions reported depending on density.

**Herbicide resistance:**

Biotypes have been reported to be resistant to ALS and photosynthesis inhibitors.

Reduced sensitivity to glyphosate has been reported in some areas.



**Figure 24.22. Common lambsquarters.** (Photos courtesy of Mike Moechnig, SDSU)



### **Kochia (*Kochia scoparia*)**

**Time of emergence:** Kochia emerges at or before planting of spring wheat.

**Life cycle and reproduction:** Annual plant that reproduces by seed.

**Distinguishing characteristics:** Kochia seedlings can be very small with over 1,000 present in a 1 ft<sup>2</sup> area. Leaf margins are fringed with hair. Leaf surfaces range from being without hairs to very hairy. Wind-blown plants will disburse seed in the fall. Found in disturbed sites.

**Yield loss potential:** Yield losses of up to 40% have been reported.

**Herbicide resistance:** Some kochia biotypes are resistant to atrazine, ALS-inhibitors, and auxin (e.g., dicamba) herbicides. Most populations in South Dakota are resistant to ALS-inhibitors.



**Figure 24.23. Kochia.** (Photos courtesy of Mike Moechnig, SDSU)

### **Canada thistle (*Cirsium arvense*)**

**Time of emergence:** Canada thistle typically emerges before or just at spring wheat planting.

**Life cycle and reproduction:** This perennial has deep extensive root systems and spreads by seeds or pieces of rhizome transported from one location to another on equipment.

**Distinguishing characteristics:** Emerging plants are very small. Leaves are opposite and small spines on the leaf margins. Canada thistle has both male and female plants. Plants are often seen in dense colonies. Found in disturbed sites.

**Yield loss potential:** Up to a 30% yield reduction have been reported with 4 shoots or more per ft<sup>2</sup>.

**Herbicide resistance:** Some biotypes have been reported to be resistant to auxin-type herbicides.



**Figure 24.24. Canada thistle.** (Photos courtesy of Mike Moechnig, SDSU)

### Field bindweed (*Convolvulus arvensis*)

**Time of emergence:** Field bindweed emerges in late spring to early summer.

**Life cycle and reproduction:** This perennial can grow from rhizomes or seed.

**Distinguishing characteristics:** Leaves are arrow-shaped on a twining stem. The root system can be extensive and deep-rooted. Flowers are white to pink and bell or trumpet shaped. It grows well in dry soils.

**Yield loss potential:** Yield losses up to 50% have been reported. Vining nature of the plant can cause problems with harvest equipment.

**Herbicide resistance:** This plant may not be sensitive to glyphosate, particularly when applied in the spring. Some biotypes are resistant to auxin-type herbicides.



**Figure 24.25. Field bindweed.** (Photo courtesy of Mike Moechnig, SDSU)

### Wild mustard (*Sinapis arvensis* syn. *Brassica kaber*)

**Time of emergence:** Wild mustard typically emerges before or at planting of spring wheat.

**Life cycle and reproduction:** Annual erect plant, reproducing by seed.

**Distinguishing characteristics:** Cotyledons (seed leaves) are kidney shaped. Leaves are alternate with hairs on the bottom of the leaf. Lower leaves are deeply lobed, whereas upper leaves are coarsely toothed. Flowers are yellow and seeds are found in a thin pod, known as a silique. Often found in disturbed sites.

**Yield loss potential:** 1 plant per ft<sup>2</sup> can reduce yields 10%. Populations of 4 per ft<sup>2</sup> can reduce yields 50%.

**Herbicide resistance:** Biotypes have been found to be resistant to ALS-inhibitor herbicides.



**Figure 24.26. Wild mustard.** (Photos courtesy of Mike Moechnig, SDSU)

### Field pennycress (*Thlaspi arvense*)

**Time of emergence:** Field pennycress is a winter annual that may germinate in fall or early spring.

**Life cycle and reproduction:** Annual erect plant that reproduces by seed.

**Distinguishing characteristics:** Cotyledons (seed leaves) are oval or oblong. Young plant is a basal rosette (growth habit resembling a dandelion) with stem elongation during flower development. Young leaves are generally oval and without hair. Leaves on the elongated stem are narrow and lance-like, but with a toothed margin. Seeds are in silicles that have the penny-shaped appearance and give the plant its common name. A garlicky odor is produced when the plants are damaged.

**Yield loss potential:** It may not reduce yield but causes problems during harvest or dockage due to off flavor of grain.

**Effective management:** ALS herbicides in the sulfonylurea or imidiazolinone group, auxin-type herbicides such as 2,4-D and MCPA.

**Herbicide resistance:** Biotypes in the U.S. have been reported to be resistant to ALS-inhibitor herbicides.



Figure 24.27. Field pennycress. (Photos courtesy of Mike Moechnig, SDSU)

### Prickly lettuce (*Lactuca serriola*)

**Time of emergence:** Prickly lettuce seed can germinate in the fall or spring.

**Life cycle and reproduction:** Depending on weather conditions, it can be an annual (1-yr cycle to produce seed) or biennial (first yr rosette only and second yr sets seed) plant, reproducing by seed that produces a plume to aid wind dispersal much like a dandelion.

**Distinguishing characteristics:** Cotyledons (seed leaves) are oval or oblong with spiny margins and spines along the midrib of the leaf. The young plant is a basal rosette (growth habit resembling a dandelion) with stem elongation during flower development. Plant exudes milky sap when cut. Leaves on the elongated stem are alternate and leaf bases clasp the stem. Flowers are yellow in color and petals have a toothed margin. Found in disturbed sites.

**Yield loss potential:** About 1 per ft<sup>2</sup> has been shown to reduce wheat yield by 15%.

**Herbicide resistance:** Biotypes of prickly lettuce that are resistant to ALS inhibitor herbicides and synthetic auxin (2,4-D type) have been reported in the U.S.



Figure 24.28. Prickly lettuce. (Photos courtesy of Mike Moechnig, SDSU)



### Flixweed (*Descurainia sophia*)

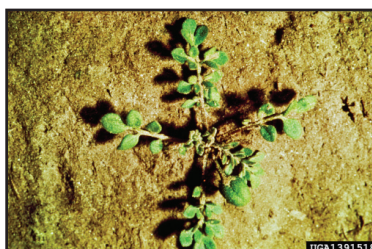
**Time of emergence:** Flixweed seeds can germinate in fall or spring.

**Life cycle and reproduction:** Annual or biennial erect plant that reproduces by seed.

**Distinguishing characteristics:** Leaves are finely divided and pinnately compound, grayish-blue in color. Juvenile plants have ovate shaped leaves in a rosette arrangement, deeply lobed margins, and the leaves are covered in star-shaped hairs. Flower petals very small, yellow or greenish-yellow. Flixweed is distinguished from other mustards by its finely dissected leaves.

**Yield loss potential:** No specific information is available at this time.

**Herbicide resistance:** Biotypes of flixweed in Kansas winter wheat have been reported to be resistant to ALS-inhibitor herbicides (sulfonylurea and imidazolinone types) <http://www.weedscience.org/Case/Case.asp?ResistID=5404>



**Figure 24.29. Flixweed.** (Photos courtesy of John D. Byrd, Mississippi State University, Bugwood.org and Mary Ellen (Mel) Harte, Bugwood.org)

### Tansymustard (*Descurainia pinnata*)

**Time of emergence:** Tansymustard is a winter annual weed that germinates in fall or spring.

**Life cycle and reproduction:** Generally a winter annual reproducing by seed.

**Distinguishing characteristics:** Leaves are finely divided and pinnately compound greener in color than flixweed. Juvenile plants have ovate shaped leaves in a rosette arrangement, deeply lobed margins, and the leaves are covered in star-shaped hairs. Flower petals very small, yellow or greenish-yellow and blooms earlier than flixweed. The fruits (pods) of tansymustard are siliques, the seeds are arranged in two rows, and are about ½ inch long; whereas, seeds of flixweed are arranged in a single row along a pod that is typically 1 to 1 ½ inches long.

**Yield loss potential:** No specific information is available at this time.

**Herbicide resistance:** No resistant biotypes have been reported.



**Figure 24.30. Tansymustard.** (Photos courtesy of Mike Moechnig, SDSU)

**Additional plant identification information and references**

Johnson, J.R., and G.E. Larson. 1999. *Grassland Plants of South Dakota and the Northern Great Plains*. SDSU Ag Communications, SDSU, Brookings, SD.

Larson, G.E., and J. R. Johnson. 1999. *Plants of the Black Hills and Bear Lodge Mountains*. SDSU Ag Communications, SDSU, Brookings, SD.

South Dakota Weeds. 2002 Revision. South Dakota Department of Agriculture and SDSU Extension, Brookings, SD.  
Stubbendieck, J., M.J. Coffin, and L.M. Landholt. 2003. *Weeds of the Great Plains*. Nebraska Department of Agriculture.

Other images and information available at <http://www.ipm.ucdavis.edu/>

**Additional yield loss information and references**

[http://www1.agric.gov.ab.ca/\\$Department/deptdocs.nsf/all/crop1280](http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/crop1280) (accessed December 2010)

**Control and herbicide resistance information**

International Survey of Herbicide Resistant Weeds. <http://www.weedscience.org/in.asp>

Moechnig, M., D.L. Deneke, and L.J. Wrage. Weed control in small grain and millet. FS525A. South Dakota State University, SDSU Extension, Brookings, SD. (please see current year's factsheet for up-to-date herbicide information).

**Acknowledgments**

South Dakota Wheat Commission, South Dakota Drought Tolerance Center, USDA-NIFA, and the South Dakota Agricultural Experiment Station.

---

Clay, S.A. 2012. Weed identification. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.



## CHAPTER TWENTY-FIVE

# Weed Management in Spring and Winter Wheat

Michael Moechnig ([Michael.Moechnig@sdstate.edu](mailto:Michael.Moechnig@sdstate.edu))

### **Introduction**

The objective of this chapter is to discuss general weed management options and strategies for spring and winter wheat. Wheat, when planted in rotation with corn and soybeans, can be used to reduce selection for herbicide resistant weeds. The early emergence of spring or winter wheat enables wheat to gain an early season growth advantage relative to many common weed species. This can help suppress weeds that escape herbicide treatments. In addition, the introduction of new herbicides and herbicide-tolerant wheat varieties have made weed management more effective. In this chapter, weed management strategies will be described based on the weed species present and application timing.

### **Challenging weed species**

Despite wheat's competitive ability, there are many weed species that can persist and multiply in small grains. The potential for a weed species to flourish in small grains depends on its emergence time, ability to grow quickly, and its seed production potential. Table 25.1 includes some of the most common weed species in South Dakota wheat.

Table 25.1. Common grass and broadleaf weed species in South Dakota wheat <sup>1</sup> .	
Grass weed species	Broadleaf weed species
1. Brome or “cheatgrass” (downy or Japanese brome)	1. Kochia
2. Foxtails (green or yellow)	2. Wild buckwheat
3. Wild oats	3. Prickly lettuce
4. Barnyardgrass	4. Common ragweed
5. Witchgrass	5. Mustard species

<sup>1</sup>Weeds are not arranged in order of frequency across the state.

### ***Perennial weed species***

Although perennial weeds can be very competitive in wheat, there are several management options. Noxious perennial weeds, such as Canada thistle and field bindweed (or creeping Jenny), are particularly problematic in seed production fields where noxious weed seed is prohibited. Both of these species can be suppressed with 2,4-D. Clopyralid (found in WideMatch®) may be more effective than 2,4-D on Canada thistle. Since these perennial weeds will often continue growth after wheat harvest, a fall glyphosate application in wheat stubble can effectively reduce densities in subsequent crops.



Figure 25.1. Canada thistle growing in wheat.



Figure 25.2. Field bindweed flowers and leaves.

Perennial grass weed species can also be a problem. Perhaps one of the most problematic perennial grass weed species is foxtail barley. Foxtail barley is most prevalent in wet, alkaline soils in no-till fields. It can be difficult to control because it matures early (approximately late May), at which time herbicides are no longer effective. In addition, herbicides registered for foxtail barley control, such as those containing propoxycarbazone (Olympus® and Rimfire®), may only provide suppression. In one study conducted in eastern South Dakota, no post-emergence grass herbicide had activity on foxtail barley. Consequently, it may be critical to control foxtail barley with a burndown application of glyphosate prior to spring wheat emergence.



Like many other perennial weeds, foxtail barley may also be controlled with fall glyphosate applications in the wheat stubble. In some cases, both spring and fall glyphosate applications are necessary for optimum control (Blackshaw et al. 1999). Other perennial grass weed species, such as quackgrass, are usually not very problematic in wheat, but including wheat in crop rotations can increase the potential for quackgrass establishment and increased densities in subsequent crops. Some herbicides that are active on downy brome, such as propoxycarbazone, sulfosulfuron, or pyroxsulam, may also suppress quackgrass.



**Figure 25.3. Foxtail barley at maturity.**



**Figure 25.4. Young foxtail barley plant that may be present at the time of the burndown herbicide application prior to spring wheat planting.** May be identified by the clasping auricles, or finger-like appendages, at the base of the leaf (inset). Quackgrass also has similar leaf characteristics, but foxtail barley is a clump-type perennial with fibrous roots whereas quackgrass has thicker, "cord-like" rhizomatous roots.

### ***Winter annual weed species***

Winter annual weed species, such as brome or "cheatgrass" (downy or Japanese brome) and mustards, can be a problem because they emerge at approximately the same time as winter wheat in the fall and resume growth with wheat in the spring. Consequently, properly timing herbicide applications can be difficult because weather conditions can be challenging in the fall because it can be difficult to distinguish brome seedlings from wheat seedlings. Brome can mature rapidly in the spring making them less susceptible to many herbicides.

Downy and Japanese brome must be treated with herbicides in the fall for optimal control. These brome species are often incorrectly referred to as "cheatgrass." Fall herbicide applications can result in nearly complete control whereas spring herbicide applications

may result in 50 to 70% control. Herbicides applied in the spring must be applied early (late April to early May) to increase their effectiveness. If fall moisture is adequate or winter wheat is planted late, it may be possible to control early emerging brome populations with a fall glyphosate burndown application, but this is not a standard recommended practice.

Generally, ALS-inhibiting herbicides such as propoxycarbazone (Olympus®), sulfosulfuron (Maverick®), or pyroxsulam (PowerFlex®) are applied in the fall (early to mid-October) after the winter wheat and brome species have emerged. SDSU trials have demonstrated that these herbicides often result in similar control, so people may select products based on price and rotation restrictions. One common challenge with fall applications is that cold weather can injure the brome species (causing purple discoloration or necrosis), which can reduce its susceptibility to herbicides (Figure 25.7). Nevertheless, fall applications generally result in more consistent control than spring applications.

Another concern regarding brome control is herbicide resistance. Since current standard brome herbicides are a similar mode of action, resistance to one product would result in resistance to all amino acid synthesis (ALS) inhibitor mode of action herbicides. ALS herbicides include Olympus®, Maverick®, PowerFlex®, Everest/PrePare®, and Beyond®.

Herbicide-resistant brome biotypes have been identified in Kansas and could occur in continuous winter wheat fields in South Dakota. Consequently, it is important to include crop rotations with winter wheat to enable the use of alternative herbicides, which will minimize selection for herbicide-resistant brome biotypes. Since brome seed is usually relatively short-lived in the soil (approximately three years), crop rotations are an effective component of brome management programs (Chepil 1946; Rydrych 1974; Wicks 1997).



**Figure 25.5. Downy brome seedlings can be differentiated from wheat seedlings as downy brome has soft hairs covering the entire plant. In addition, many brome species will have slightly twisted leaves.**



**Figure 25.6. Downy brome (top) can be distinguished from Japanese brome (bottom) by the long awns on the tips of the downy brome seed heads, which gives a more “feathery” appearance. This distinction can be important for selecting future herbicide programs because downy brome is generally more difficult to control than Japanese brome.**





**Figure 25.7.** Downy brome injured by cool temperatures in the fall, which can reduce its susceptibility to herbicides.

Feral rye and jointed goatgrass are also winter annual weed species that can be difficult to control with herbicides partially because they have similar genetic characteristics as wheat. Herbicide-resistant wheat varieties, such as ClearField wheat, are necessary to control these weed species. ClearField wheat technology protects the plant from some ALS herbicides, such as imazamox (Beyond®). Plants in this category are herbicide resistant and are not classified as genetically modified organisms. Additional information on using this technology effectively is available at <http://www.agproducts.basf.com/products/research-library/cl-wheat-stewardship-tib-2010.pdf>.

Feral rye can be a problem in several areas in central and western South Dakota, whereas jointed goatgrass is generally a problem in a few locations in southwestern South Dakota.

There are also several problematic winter annual broadleaf weed species, such as wild mustard, field pennycress, bushy wallflower, and tansymustard. These species can also grow as annual weed species by germinating in the spring. The most effective herbicides for these species are generally 2,4-D or ALS-inhibiting herbicides such as thifensulfuron (Harmony®), tribenuron (Express®), metsulfuron (Ally®), and others.

Several of the ALS-inhibiting herbicides used to control downy or Japanese brome will also control several winter annual weed species in the mustard (Brassicaceae) plant family, which includes the weed species mentioned above. As with the winter annual grass weed species, crop rotations can disrupt the life cycle of these weed species, which can help reduce the weed seed banks.

### ***Annual grass weed species***

The most common annual grass weed species in South Dakota spring wheat include green foxtail, yellow foxtail, barnyardgrass, and wild oats. Although annual grass species may not be highly competitive in spring wheat, their populations can become high enough to cause measureable yield loss (Peterson and Nalewaja, 1991 and 1992). If not properly managed, spring wheat crops can facilitate increases in the seed banks of annual grass weed species as some can continue growing and produce seed after wheat harvest.

There are several herbicide options to control annual grass weed species, but it is important to correctly identify the grass species as herbicide options and rates can vary among weed species. Some ALS-inhibiting herbicides, such as mesosulfuron (e.g., Silverado® and Rimfire®) intended for grass control may be very effective on wild oats, but not foxtail species. Several herbicides intended for foxtail control are more effective on green foxtail than yellow foxtail so rates may need to be adjusted when controlling these species. Fenoxaprop (e.g., Puma®) is an example of an herbicide that has different recommended rates for green foxtail, yellow foxtail, and wild oats.



**Figure 25.8.** Yellow foxtail may be distinguished by the relatively long hairs at the leaf base, whereas other areas on the shoot are hairless.



**Figure 25.9.** Green foxtail can be distinguished by the lack of hairs on the leaves or stems. Like other foxtail species, green foxtail has fringed ligule or collar at the leaf base. Wild oats has a longer membranous ligule.



**Figure 25.10.** Foxtail species may also be distinguished by their seed as yellow foxtail has much larger seeds than green foxtail.

Persian darnel may be a relatively new annual grass weed species of concern in South Dakota. Persian darnel is established in several locations in North Dakota and eastern Montana, and now there are reports of this weed in northwestern South Dakota. Due to its relatively short stature, it can be difficult to detect in wheat. However, high densities can result in 80% spring wheat yield loss (Holman et al. 2004). Some effective herbicides may include pinoxaden (Axial®), propoxycarbazone (Rimfire®), and imazamox (Beyond®, for ClearField wheat only).

#### ***Annual broadleaf weed species***

In many cases, it is necessary to use more than one herbicide chemistry to control all broadleaf weed species present in wheat fields. Kochia is likely one of the most common weed species found in wheat. It can be difficult to control since most populations are now resistant to ALS-inhibiting herbicides. Fluroxypyr (e.g., Starane® and several others) is a growth regulator herbicide that is likely the most effective herbicide for kochia control, but it is not highly effective on many other broadleaf weed species.

Bromoxynil (e.g., Buctril® and several others) is a photosynthesis-inhibiting herbicide that is not as effective on kochia as fluroxypyr, but it has activity on wild buckwheat and several other annual broadleaf weed species. Consequently, these are likely among the most commonly used herbicides and they are a component of several premixed herbicide products.

Wild buckwheat is also controlled with some ALS-inhibiting herbicide products or growth regulator herbicides such as clopyralid (found in WideMatch®) or dicamba. The presence of other broadleaf weed species may influence the need for additional herbicide tank mix partners. For example, prickly lettuce control may require including a growth regulator herbicide such as 2,4-D, dicamba, or clopyralid.

Pigweed species, common lambsquarters, and mustard species may be best controlled with ALS-inhibiting herbicides (Harmony®, Express®, Affinity®, Ally®, and several others) or growth regulator herbicides such as 2,4-D. Premixed herbicide products are becoming more common for controlling mixtures of several different broadleaf weed species or grass and broadleaf weed species. In some cases, MCPA or 2,4-D may be added to these premixes as a relatively inexpensive way to improve the control of difficult weeds and provide protection against many minor broadleaf weed species.

## HERBICIDE APPLICATION TIMING

### ***Post-emergence applications***

Proper herbicide application timing is critical to avoid wheat injury and maximize weed control. The targeted application period for many post-emergence herbicides is from wheat tillering to jointing, which is the time when stem nodes become visible. Timing dicamba (between 4- and 6-leaf spring wheat) or 2,4-D (5-leaf stage to jointing) applications is particularly important as late applications can injure developing reproductive tissue and cause wheat head deformities.

Many 2,4-D labels suggest it may be applied in wheat until the early boot stage (immediately prior to head emergence), but the risk of wheat injury increases if 2,4-D is applied after jointing. The targeted application period can vary among herbicide products, so it is important to be aware of the application directions on the herbicide labels and to be aware of wheat development in the field in order to make well-timed herbicide applications.

### ***Burndown or pre-emergence applications***

Non-selective herbicides, such as glyphosate or paraquat (Gramoxone®), may be applied prior to wheat emergence to control emerged weeds. It is recommended to apply these herbicides immediately prior to wheat planting. People occasionally plan to apply these herbicides after seeding, but prior to emergence. In some cases, adverse weather conditions can delay the herbicide application, which produces an environment where wheat emerges before the herbicide is applied (Figure 25.11). This creates a very challenging situation because the weeds may be much larger than the wheat and the new wheat seedlings are too small to tolerate many common post-emergence herbicides.



**Figure 25.11. Emerging wheat may be sensitive to many burndown herbicides.**

Some herbicides are available for tank-mixing with glyphosate to increase control of difficult weed species and provide soil residual activity to suppress or control weeds emerging after crop emergence. Flucarbazone (PrePare®) is one herbicide that may be applied prior to weed emergence to provide residual control of grass species such as green foxtail or wild oats. Flucarbazone also has foliar activity to help control mustard species or downy brome that may be emerged prior to wheat planting. In addition, flucarbazone may also be applied after wheat emergence.

Saflufenacil (Sharpen®) may only be applied prior to wheat emergence to provide residual broadleaf weed control. Saflufenacil also has foliar activity to help control emerged broadleaf weed species at the time of application.

Herbicides are being developed for application prior to winter wheat emergence that will provide residual control of downy or Japanese brome. Therefore, residual herbicide options are increasing which may improve weed management flexibility in winter and spring wheat.

### ***Pre-harvest applications***

Herbicides are occasionally applied immediately prior to harvest if the weeds are still present at levels that will inhibit combining, or if the grain is intended to be sold as certified seed. Pre-harvest herbicide options include 2,4-D (ester or amine), dicamba (Clarity®), metsulfuron (Ally®), carfentrazone (Aim®), or glyphosate. Glyphosate is an appealing option because of its price and the large number of weeds it controls. However, pre-harvest glyphosate applications are not recommended for fields intended for seed production because it can inhibit wheat germination and seedling vigor if applied too early (when wheat seed moisture is greater than 30%).

In SDSU trials, glyphosate application at 50% seed moisture did not greatly reduce wheat seed germination. However, the resulting seedlings were noticeably stunted or deformed. All pre-harvest herbicides should be applied after the hard dough stage, which is approximately the time when wheat seed moisture is less than 30%.

At the hard dough stage, most of the maturing wheat plants will be necrotic (dead) and the stem nodes (joints) will have lost nearly all green color. This is the time when the wheat plants have reached maturity and grain fill is nearly complete. Since the herbicides will be applied to a dense canopy, it may be beneficial to increase the water carrier rate as much as possible. Labels for several of these herbicides suggest that carrier rates may be as low as ten gallons per acre, but 15–20 gallons may provide more consistent results.



Pre-harvest herbicide applications should be viewed as a rescue treatment in seed fields as the use of any product may reduce wheat seed viability. After harvest, wheat germination should be checked if the seed is intended for planting.

### ***Post-harvest applications***

Several weed species may continue to grow after wheat harvest and produce seed that may increase future weed populations. To prevent this, non-selective herbicides, such as glyphosate, may be applied to control weeds prior to weed seed production. This is also a good time to control perennial weeds such as dandelions, field bindweed, and Canada thistle. Sometimes 2,4-D or dicamba may be applied alone or together for general broadleaf weed control or with glyphosate to improve perennial weed control. However, opportunities to use 2,4-D or dicamba can be limited due to the risk of off-site droplet or vapor movement to neighboring susceptible broadleaf crops such as soybeans, sunflowers, or alfalfa.

### ***Herbicide tank mixes***

When applying herbicide mixtures, it may be important to check the labels for tank-mixing compatibility. Mixing herbicides may reduce activity or increase the risk of crop injury. For example, high rates of bromoxynil can reduce the activity of grass herbicides such as fenoxaprop.

Mixing herbicides with similar modes of action can occasionally increase the risk for crop injury, particularly among sensitive varieties. For example, mixing two ALS-inhibiting herbicides (one for broadleaf and one for grass control) can increase the risk of temporary crop discoloration. However, in some cases, tank mixtures can be utilized to reduce the risk for crop injury. For example, tank-mixing 2,4-D with tribenuron (Express®) can reduce the risk of temporary crop yellowing that can occasionally be caused by tribenuron.

Although negative interactions among herbicides may be less common now than in the past, always check label guidelines for compatibility when mixing herbicide chemistries. In addition, it may be important to be aware that increasing the number of chemical mixes increases the probability of an unexpected and undesirable outcome.

Unexpected injury can also occur when herbicides are mixed with other pesticides. For example, tank-mixing bromoxynil herbicides with fungicides formulated as emulsifiable concentrates can occasionally cause temporary leaf necrosis. This interaction may be most common when weather conditions are cool at the time of application. Although injury may initially appear harmful, wheat often quickly grows out of the injury symptoms without a yield loss (Wiersma et al. 2005).



**Figure 25.12. Wheat leaf tip necrosis caused by bromoxynil.**

## HERBICIDE CARRYOVER

### *Wheat injury from herbicide carryover*

Most herbicides used in corn, soybeans, or sunflowers do not restrict rotations with wheat. However, atrazine carryover after corn could potentially cause wheat injury. Generally, wheat may tolerate up to 0.15 lbs/A atrazine in the upper three inches of the soil surface. This tolerance will vary among soil types as the carryover risk may be greater on coarse texture, low organic matter (less than 2%), and high pH soils (greater than 7).

For most fields, atrazine is not a risk to spring wheat because research suggests that under normal growing conditions 90% or more of the applied atrazine is depleted over a year. However, the same may not be true for high risk soils. We recommend that in high-risk soils, atrazine be avoided for the year preceding wheat.

### *Carryover of wheat herbicides*

Including wheat in crop rotations can help reduce weed populations, but it is important to select herbicides that do not persist and risk injury to subsequent crops. Herbicide carryover is particularly problematic when the wheat crop is unexpectedly lost due to severe weather, such as hail, and an alternative crop may be planted. Metsulfuron is an example of an herbicide that is effective on several broadleaf weed species and is relatively inexpensive, but it has a relatively high risk for carryover injury to crops such as sunflower and safflower.

Many herbicides used to control downy or Japanese brome have a potential to cause carryover injury to field corn, particularly if the herbicides are applied in the spring as a rescue treatment. Therefore, it is important to check for rotational crop restrictions when selecting appropriate herbicides for weed control.

### *Cover crops*

Labels are generally vague or do not specify rotation restrictions for cover crop species that may be planted in wheat stubble. The risk of herbicide injury to cover crops may increase in coarse texture soils, soils with low organic matter, or high soil pH. Perhaps the herbicides with the greatest carryover risk include metsulfuron (e.g., Ally®) or several herbicides used for downy or Japanese brome control. Table 25.2 provides estimates of the potential risk associated with different herbicides on different cover crop species. Additional information on cover crops is available in Chapter 7.



Table 25.2. Potential risk estimates using different herbicides on different cover crop species.  
(Source: M. Moechnig, SDSU)

Herbicide	Application timing	Cover crop risk <sup>1</sup>							
		Lower	Moderate	High	Other grasses (legume, hairy vetch)	Other grasses (legume, hairy vetch)	Other grasses (legume, hairy vetch)	Other grasses (legume, hairy vetch)	Other grasses (legume, hairy vetch)
Maverick (sulfosulfuron)	Fall	22	22	22	22	22	22	22	22
Chrypus Flex (pyrazoxycarbonyl + mesosulfuron)	Fall	24	12-24	12	12-24	4	12	12	24
Rimfire (pyrazoxycarbonyl + mesosulfuron)	Spring	10	10	10	10	0-4	12	10	10
Powerflex (pyrazoxycarbonyl)	Fall	9	9	9	9	1	9	9	9
GoldShy (pyrazoxycarbonyl + thifluralin + fluroxypyr)	Spring	9	9	9	9	1	9	9	9
Everest (mesosulfuron)	Spring	24	9-24	9-24	9-24	4-11	11-24	9	11-24
Coyote (mesosulfuron)	Spring	3	3	18-26	9-18	4-9	9	9	9-18
Aly (mesosulfuron)	Spring	22	22	22	22	1-10	12	22	22
Harmony (thifluralin)	Spring	1-2	1-2	2	2	0	1-2	1-2	1-2
Express (thifluralin)	Spring	1-2	1-2	2	2	0	1	1-2	1-2
Beck's (fluroxypyr)	Spring	1	1	1	1	1	1	1	1
Huskie (pyrazoxycarbonyl + fluroxypyr)	Spring	9	9	9	9	0-4	4	9	9
WideMatch (clopyralid + fluroxypyr)	Spring	11	18	4	4	0	11	18	4
Starane (fluroxypyr)	Spring	4	4	4	4	4	4	4	4

<sup>1</sup>This table is intended to provide general risk approximations. Prior to planting, verify rotation restrictions on the herbicide label, or with the herbicide retailer. Carryover restrictions may vary by soil characteristics and precipitation totals. Consult a business if uncertain about the carryover risk.

## Herbicide resistance

Few weeds in wheat have been identified as herbicide resistant. Kochia resistance to ALS-inhibiting herbicide has become widespread and is likely present in most wheat fields. In many wheat fields, approximately half the kochia population may be resistant to ALS-inhibiting herbicides.

Wild oat resistance to fenoxaprop has been identified in central and eastern South Dakota. These biotypes may be controlled with ALS-inhibiting herbicides, such as mesosulfuron (Silverado® or Rimfire®).

There is one field in central South Dakota, however, where it is suspected that the wild oat population may be resistant to ACCase-inhibiting herbicides, such as fenoxaprop (Puma®), and ALS-inhibiting herbicides. Consequently, there may be no other herbicide options for controlling wild oats in that scenario. In this particular field, wheat has been grown continuously for several years. This demonstrates the importance of crop and herbicide rotation to minimize the risk of selecting for herbicide-resistant weed biotypes.

Downy and Japanese brome are two weed species that would be particularly problematic if resistant biotypes were selected since only one herbicide mode of action registered in South Dakota is effective on these weed species. Biotypes resistant to ALS-inhibiting herbicides have been identified at several locations in Kansas. In these fields, there are no other registered herbicides that may be effective for downy brome control. Therefore, it is critical to rotate herbicides, crop species, and apply herbicides at appropriate rates, times, and with appropriate adjuvants to help prevent selection for herbicide resistant weed biotypes.

#### Additional information and references

Blackshaw, R.E., G. Semach, X. Li, J.T. O'Donovan, and K.N. Harker. 1999. An integrated weed management approach to managing foxtail barley (*Hordeum jubatum*) in conservation tillage systems. *Weed Technology* 13:347-353.

Chepil, W.S. 1946. Germination of weed seeds. Longevity, periodicity of germination, and vitality of seeds in cultivated soil. *Sci. Agr.* 26:307-346.

Holman, J.D., A.J. Bussan, B.D. Maxwell, P.R. Miller, and J.A. Mickelson. 2004. Spring wheat, canola, and sunflower response to Persian darnel interference. *Weed Technology* 18:509-520.

Peterson, D.E., and J.D. Nalewaja. 1991. Green foxtail (*Setaria viridis*) competition with spring wheat (*Triticum aestivum*). *Weed Technology* 6:291-296.

Peterson, D.E., and J.D. Nalewaja. 1992. Environment influences green foxtail (*Setaria viridis*) competition with wheat (*Triticum aestivum*). *Weed Technology* 6:607-610.

Rydrych, D.J. 1974. Competition between winter wheat and downy brome. *Weed Science* 22:211-214.

Wicks, G.A. 1997. Survival of downy brome (*Bromus tectorum*) seed in four environments. *Weed Science* 45:225-228.

Wiersma, J.J., B.R. Durgan, and J.H. Cameron. 2005. Potential for crop injury in spring wheat when tank mixing several fungicides with several common grass and broadleaf herbicides in 2005 at Crookston, MN. *North Central Weed Science Society Research Report* 62:26-27.

#### Acknowledgements

Support provided by the South Dakota Wheat Commission and South Dakota State University.

---

Moechnig, M. 2012. Weed management in spring and winter wheat. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.

*The information in this chapter is provided for educational purposes only. Product trade names have been used for clarity, but reference to trade names does not imply endorsement by South Dakota State University; discrimination is not intended against any product. The reader is urged to exercise caution in making purchases or evaluating product information. Label registrations can change at any time. Thus the recommendations in this chapter may become invalid. The user must read carefully the entire, most recent label and follow all directions and restrictions.*



## CHAPTER TWENTY-SIX

# Wheat Herbicide Injury

Sharon A. Clay ([Sharon.Clay@sdstate.edu](mailto:Sharon.Clay@sdstate.edu))

Failure to follow a pesticide label or plants experiencing drift or tank contamination can exhibit dramatic, yet characteristic plant symptoms. If the damage occurs early and is not severe, yield loss may not occur. However, if injury occurs during a critical growth stage or is severe, the damage may result in a total crop loss. The purpose of this section is to describe and illustrate typical plant symptoms due to herbicide injury and to discuss the mechanism or mode of action of commonly used herbicides. Symptoms and images of selected herbicides are provided below.

Herbicides have been characterized by the method that the herbicide controls susceptible plants. The method is the mechanism or mode of action groups. Herbicides that have a similar mechanism of action within a plant have similar symptoms or impacts on wheat. These categories are provided in Table 26.1.

A more complete discussion is provided at <http://wssa.net/Weeds/Resistance/WSSA-Mechanism-of-Action.pdf>. To minimize resistance, where possible, weed management strategies should integrate herbicides with different mechanisms of action.

Table 26.1. WSSA suggested group number, mechanism-of-action (MOA), and herbicide chemistry examples.

MOA Group	Mechanism	Herbicide Chemistry Examples
1	ACETYL COA CARBOXYLASE (ACCase) INHIBITORS	Aryloxyphenoxypropionate (FOPs) Cyclohexanedione (DIMs) Phenylpyrazolin (DENs)
2	ACETOLACTATE SYNTHASE (ALS) or ACETOHYDROXY ACID SYNTHASE (AHAS) INHIBITORS	Imidazolinones (Imis) Pyrimidinylthiobenzoates Sulfonylaminocarbonyltriazolinones Sulfonylureas (SU) Triazolopyrimidines
3	MICROTUBULE ASSEMBLY INHIBITOR	Benzamide Benzoic acid (DCPA) Dinitroaniline Phosphoramidate Pyridine
15	VERY-LONG-CHAIN FATTY ACID INHIBITOR	Acetamide Chloroacetamide Oxyacetamide Tetrazolinone herbicides
23		Carbetamide, chlorpropham, and propham (Note: Group 23 types of herbicides are no longer or very rarely used in U.S. crop production.)
4	SYNTHETIC AUXINS	Benzoic acids Phenoxycarboxylic acids Pyridine carboxylic acids Quinoline carboxylic acids
5	PHOTOSYSTEM II INHIBITORS Site A	Phenylcarbamates Pyridazinones Triazines Triazinones Uracils
6	Site B	Benzothiadiazinones Nitriles Phenylpyridazines
7	Site A but binds differently than Group 5	Amide Ureas
8	FATTY ACID AND LIPID BIOSYNTHESIS INHIBITORS	Phosphorodithioates Thiocarbamates
16		Benzofuranes
9	ENOLPYRUVYL SHIKIMATE-3-PHOSPHATE (EPSP) SYNTHASE INHIBITORS	Glycines (glyphosate)
10	GLUTAMINE SYNTHETASE INHIBITORS	Phosphinic acids (glufosinate and bialophos)
11	CAROTENOID BIOSYNTHESIS INHIBITORS (bleaching herbicides)	Amitrole
12		Amides Anilidex Furanones Phenoxybutan-amides Pyridiazinones Pyridines
13	Inhibits DOXP synthase	Clomazone
27	Inhibits 4-HPPD enzyme	Callistemones Isoxazoles Pyrazoles Triketones
14	PROTOPORPHYRINOGEN OXIDASE (PPG oxidase or Protox) INHIBITORS	Diphenylethers N-phenylphthalimides Oxadiazoles Oxazolidinediones Phenylpyrazoles Pyrimidindiones Thiadiazoles Triazolinones

17	POTENTIAL NUCLEIC ACID INHIBITORS or NON-DESCRIPT MODE OF ACTION	Organic arsenicals
25		Arylamino propionic acids
26		Unclassified herbicides
18	DIHYDROPTEROATE SYNTHETASE INHIBITORS	Carbamate herbicide Asulam
19	AUXIN TRANSPORT INHIBITORS	Phthalamates (naptalam) Semicarbazones (diflufenzopyr)
20	CELLULOSE INHIBITORS	Nitriles
21		Benzamides
28		Triazolocarboxamides
29		Alkylazine
22	PHOTOSYSTEM I INHIBITORS	Bipyridyliums
24	OXIDATIVE PHOSPHORYLATION UNCOUPLERS	Dinitrophenols (dinoterb)

(Chart adapted from University of Illinois, Weed Science–Extension)

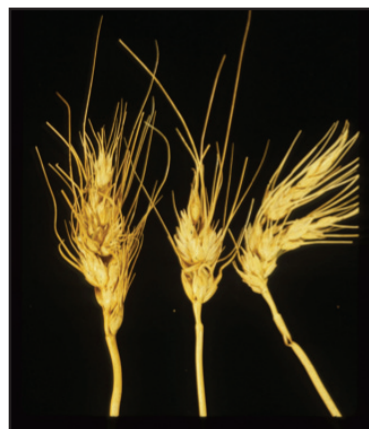
## MOA 4 – Synthetic Auxins

### PHENOXYCARBOXYLIC ACIDS

**Herbicide examples:** 2,4-D; MCPA; Stinger®

**Mechanism-of-action:** Acts as a synthetic auxin, disrupting nucleic acid metabolism and protein synthesis, which ultimately leads to plant death.

**Injury symptoms:** Most injury occurs if applied at seedling stage or at boot stage. If applied before tillering, rolled leaves and few tillers may develop. If applied after jointing, symptoms may be twisted flag leaf, abnormal heads, and sterile spikelets (Figure 26.1). MCPA has a greater window of crop safety although high application rates or late applications may result in injury.



**Figure 26.1. Head damage due to 2,4-D application.** (Photo courtesy of Leon Wrage)

#### Wheat injury symptoms from synthetic auxins

Rolled leaves  
Twisted, malformed heads  
Stalk bending and brittleness  
Missing kernels in spike

#### Injury cause

Applied to rapidly growing wheat  
Applied too late

## BENZOIC ACIDS

**Herbicide example:** Dicamba (Banvel®)

**Mechanism-of-action:** Acts as a synthetic auxin, see 2,4-D.

**Injury symptoms:** Symptoms are similar to 2,4-D. Sterile spikelets may occur if applied from the jointing to boot stage. Wheat varieties vary in sensitivity. Some exhibit no injury and some show extreme symptoms.

**Images of dicamba injury:** Symptoms of dicamba injury to wheat can be found at:  
<http://www.kysmallgrains.org/productionmanual/weedmanagement.htm>

### Wheat injury symptoms from benzoic acid herbicides

Same as 2,4-D but may occur at lower application rates than 2,4-D

#### Injury cause

Variable variety sensitivity

### MOA 1 – Acetyl CoA Carboxylase (ACCase) Inhibitors (also known as Lipid Synthesis Inhibitors)

**Herbicide examples:** Diclofop (Hoelon®); clodinafop (Discover®); fenoxypop (Puma®)

**Mechanism-of-action:** Inhibits the formation of lipids used for membranes and stops growth of new tissue.

**Injury symptoms:** Can cause yellowing of wheat tips and blades soon after application (Figure 26.2). Browning and stunting of plants later. Applications after the jointing stage may result in stem breakage and lodging. Wet and cold conditions before or at the time of application can result in injury.



**Figure 26.2. ACCase inhibitor damage.**  
(Photo courtesy of Leon Wrage)

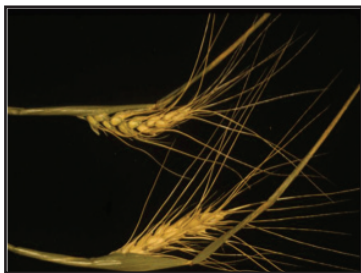


**MOA 9 – Enolpyruvyl Shikimate-3-phosphate (EPSP) Synthase Inhibitor  
(also known as Amino Acid Derivative Herbicides)**

**Herbicide example:** Glyphosate (Roundup®)

**Mechanism-of-action:** Amino acid synthesis inhibitor, stops synthesis of aromatic amino acids (those that contain a phenyl ring).

**Injury symptoms:** Yellowing on plant. Environmental conditions that slow growth (e.g., extreme heat, cold, or drought) reduce the effects of glyphosate. Youngest leaves near growing point yellow and die. If not too severe, heads may show malformation (Figure 26.3). Causes of injury may be drift from another field, misapplication after emergence, or tank contamination.



**Figure 26.3. Glyphosate damage to wheat.**  
(Photo courtesy of Leon Wrage)

**Wheat injury symptoms from EPSP synthase inhibitors**

Yellow then brown foliage  
Growing point dies

**Injury cause**

Misapplied to wheat after emergence  
Tank contamination

**MOA 10 – Glutamine Synthetase Inhibitors  
(also known as Phosphoric Acid Type Herbicides)**

**Herbicide example:** Glufosinate (Liberty®)

**Mechanism-of-action:** Glufosinate stops the conversion of glutamate + ammonia to the amino acid glutamine, resulting in the accumulation of toxic levels of ammonia in leaf tissue.

**Injury symptoms:** Symptoms appear within 3 to 5 days after treatment. Water-soaked lesions may appear and then leaves become pale yellow (such as nitrogen deficiency) or purple (may look like phosphorus deficiency).

**Images of glufosinate injury:** Symptoms of glufosinate injury to crops can be found in Ontario Ministry of Agricultural (OMAF) publication, “Herbicide Injury Gallery: Field Crops,” online at: [http://www.omafra.gov.on.ca/english/crops/facts/herbinjury\\_gallery/herbicidegal2.htm](http://www.omafra.gov.on.ca/english/crops/facts/herbinjury_gallery/herbicidegal2.htm)

**Wheat injury symptoms from Glutamine synthetase inhibitors**

Pale yellow or purple leaves  
Water-soaked lesions

**Injury cause**

Misapplied or tank contamination

## MOA 2 – Sulfonylurea (SU) Herbicides and Imidazalinone (Imi) Herbicides

**Herbicide examples:** Tribenuron (Express®), thifensulfuron (Harmony®), metsulfuron (Ally XP®)

**Mechanism-of-action:** Both SU and Imi type chemistries of herbicides inhibit the formation of branched chain amino acids.

**Injury symptoms:** Injury symptoms are slow to develop with first appearance 7 to 10 days after exposure. Sensitive plants generally show overall yellowing (chlorosis) and stunting. If applied at the correct rate, injury symptoms are often temporary. For grasses, the growing point yellows and plant slowly dies. A reduction in tiller number or spike number may occur. Symptoms may be noticed even if applied according to the label rates and timings, although plants often recover with no yield loss. SU and Imi herbicides typically are applied at low rates (ounces of active ingredient per acre) and tank contamination may be a problem. In high pH soils, carryover of the SU chemistry types may be problematic, whereas carryover of Imi chemistry type herbicides is more likely in low pH soils.

**Images of ALS injury:** Images of symptoms to wheat can be found at: [http://www.extension.umn.edu/distribution/cropsystems/components/6967\\_011.html](http://www.extension.umn.edu/distribution/cropsystems/components/6967_011.html)

### Wheat injury symptoms from SU or IMI chemistries

Stunted plant, stunted internodes  
Yellow translucent leaves  
Death of growing point  
Bottle brush roots

### Injury cause

Variety sensitivity  
Applied too late  
Tank contamination

## MOA 11, 12, 13, 27 – Carotenoid Biosynthesis Inhibitors (also known as Pigment Inhibitor Herbicides)

**Herbicide examples:** Isoxaflutole (Balance®), tembotrione (Laudis®), clomazone (Command®), mesotrione (Callisto®)

**Mechanism-of-action:** There are several herbicides with different specific mechanisms of action that are included in this group of herbicides. The common strategy among these herbicides is that enzymes in the carotenoid pigment pathway are inhibited. Carotenoids are plant pigments that include chlorophyll or protect chlorophyll from destruction.

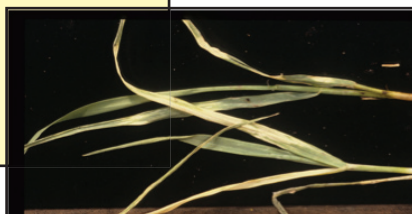
**Injury symptoms:** White areas on plants or albino plants appear during emergence. Command® carryover may be seen early in the season; plants may recover from early season injury (Figure 26.4).

### Wheat injury symptoms from Carotenoid biosynthesis inhibitors

White tissue  
Poor emergence  
Stunted plants  
Growing point dies

### Injury cause

Applied on cool, wet, or sandy soils  
Carryover problem



**Figure 26.4. Command® injury.**  
(Photo courtesy of Leon Wrage)

#### MOA 14 – Protoporphyrinogen Oxidase (PPG oxidase or PROTOX) Inhibitors

**Herbicide example:** Carfentrazone (Aim®)

**Mechanism-of-action:** Inhibits protoporphyrinogen oxidase causing a cascade of events, which eventually result in cell membrane destruction and death of the plant.

**Injury symptoms:** Appearance of necrotic (dead tissue) speckling on leaves within a few days after exposure. Symptoms are most often observed in seedlings shortly after emergence.

**Images of carfentrazone injury:** Symptoms of carfentrazone injury to crops can be found at: <http://weedscience.missouri.edu/herbinjsymptoms/cellmem.html>

##### **Wheat injury symptoms from PROTOX inhibitors**

Yellowing or reddening of new leaves  
Speckling of the older, exposed leaves  
Stunting of plant  
Death of tissue and browning  
Growing point dies

##### **Injury cause**

Misapplication  
Tank contamination

#### MOA 22 – Photosystem I inhibitors

**Herbicide example:** Paraquat (Gramoxone®)

**Mechanism-of-action:** Herbicide accepts electrons from photosystem I and forms a herbicide radical. This radical reduces molecular oxygen to form superoxide radicals. The radicals are extremely reactive and destroy membrane fatty acids, which lead to the destruction of cell membranes and cell death.

**Injury symptoms:** Symptoms are often observed within hours, especially in sunny days. Leaves develop water soaked lesions and speckling.

**Images of paraquat injury:** Symptoms of paraquat injury to crops can be found in University of Missouri Weed Science publication at: <http://weedscience.missouri.edu/herbinjsymptoms/cellmem.html>

##### **Wheat injury symptoms from Photosystem I inhibitors**

Limp leaves  
Water soaked appearance (looks like frost damage)  
Brown tissue in water soaked areas

##### **Injury cause**

Drift  
Tank contamination

## MOA 5 – Photosystem II Inhibitor - Triazine

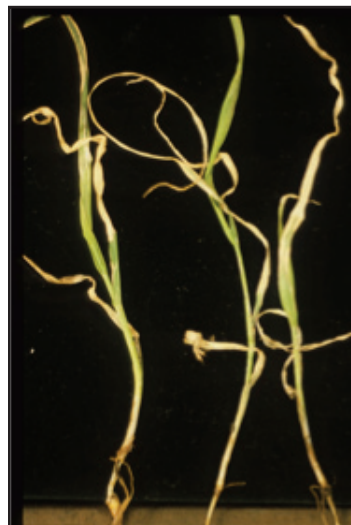
**Herbicide example:** Atrazine (Aatrex®)

**Mechanism-of-action:** Stops electron flow from  $Q_A$  to  $Q_B$  in photosystem II, which stops  $CO_2$  fixation and production of ATP and  $NADPH_2$ , which are needed for plant growth. These herbicides bind at site A. Other effects include lipid and protein oxidation, which leads to leaky cell membranes and plant death.

**Injury symptoms:** Atrazine is not labeled on wheat, but injury may occur if there is soil carryover from the previous year (Figure 26.5 and 26.6). In addition, tank contamination from previous applications may occur. Triazine injury symptoms start as yellowing of the seedling and then death of the oldest leaves. Roots are malformed. If severe, plants will not survive.



**Figure 26.5. Carryover of atrazine from previous corn crop.** (Photo courtesy of Leon Wrage)



**Figure 26.6. Atrazine injury.** (Photo courtesy of Leon Wrage)

### Wheat injury symptoms from triazine herbicides

Yellow and brown leaves

#### Injury cause

Cool wet conditions slowing wheat growth

Crop oil synergy if applied as a post emergence

## MOA 6 – Photosystem II Inhibitor - Benzonitriles

**Herbicide example:** Bromoxynil (Buctril®, Bronate®)

**Mechanism-of-action:** Stops electron flow in photosynthesis in photosystem II, but unlike atrazine, binding of the herbicide occurs at site B. The final effects are similar to atrazine.

**Injury symptoms:** Symptoms appear as leaf tip chlorosis, general wilting, speckling and necrotic lesions to tissue where application has occurred. Young tissue that emerges after application generally is unaffected. Wheat is typically tolerant to bromoxynil (unlike atrazine), but injury may occur if cool or very high temperatures occur. Recovery is generally rapid.

**Images of bromoxynil injury:** Symptoms of bromoxynil injury to wheat can be found in Ontario Ministry of Agricultural (OMAF) publication, “Herbicide Injury Gallery: Field Crops,” online at: [http://www.omafra.gov.on.ca/english/crops/facts/herbinjury\\_gallery/herbicidegal2.htm](http://www.omafra.gov.on.ca/english/crops/facts/herbinjury_gallery/herbicidegal2.htm)

### Wheat injury symptoms from benzonitrile herbicides

Yellow and brown leaves

#### Injury cause

Crop oil with the post-emergence application

## MOA 3 – Mitosis Inhibitor - Microtubule Assembly - Dinitroanilines

**Herbicide examples:** Trifluralin (Treflan®), pendimethalin (Prowl®)

**Mechanism-of-action:** Inhibit the growth of roots or shoots of seedlings by binding to tubulin, which leads to loss of microtubules assembly, structure, and function. This in turn leads to stoppage of cell division and cell wall formation.

**Injury symptoms:** Symptoms are apparent during or soon after plant emergence (Figure 26.7). Shortened, swollen root types (root clubbing), shoots are thick, short, and may be purple in color. Injury occurs if DNA herbicide is incorporated too deeply into the seeding zone. Contributing factors to increased plant injury include wet, cool soils or other stress factors such as soil compaction or drought. Carryover from a previous year’s application can occur if applied late and cool conditions have occurred.

### Wheat injury symptoms from dinitroanilines

Stunted plants

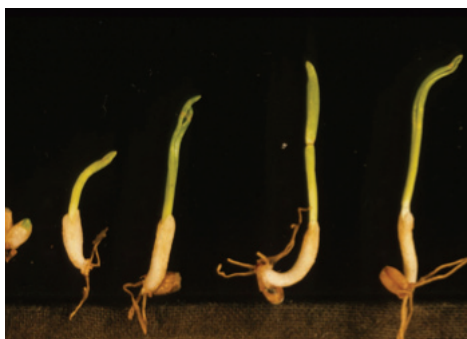
Roots short and thick

#### Injury cause

Carryover

Misapplication

Over-application



**Figure 26.7. Dinitroaniline injury.**  
(Photo courtesy of Leon Wrage)

### MOA 15 – Mitosis Inhibitor - Very-long chain Fatty Acid Inhibitor - Acetanilides

**Herbicide examples:** Metolachlor (Dual®), acetochlor (Harness®)

**Mechanism-of-action:** Growth inhibitor that stops the formation of very long fatty acids. This stoppage has effects on the formation of all cell membranes. Seedling roots and shoots of susceptible plants stop growing.

**Injury symptoms:** Death of the plant occurs soon after emergence or no plants emerge in the area.

#### Wheat injury symptoms from acetanilides

Poor emergence  
Stunted plants  
Leaf out before emergence

#### Injury cause

Over-application  
Cool, wet soils

### MOA 8 and 16 – Fatty Acid and Lipid Biosynthesis Inhibitor

**Herbicide example:** Triallate (Far-go®)

**Mechanism-of-action:** Inhibit biosynthesis of fatty acid and lipids (not through ACCase); biosynthesis of proteins; and inhibits gibberellin synthesis.

**Injury symptoms:** Appear during or soon after plant emergence. Reduction in cuticular wax deposition that may lead to increased disease or other stress severity. Injured seedlings may show reduced coleoptile length, stunting, or delayed emergence. Shoot tips may also fail to unroll from the coleoptiles giving the plant a buggy-whip appearance.

**Images of thiocarbamate injury:** Images of thiocarbamate injury on wheat can be found in the online publication, “Herbicide and Nonherbicide Injury Symptoms on Spring Wheat and Barley,” University of Minnesota Extension at: [http://www.extension.umn.edu/distribution/cropsystems/components/6967\\_011.html](http://www.extension.umn.edu/distribution/cropsystems/components/6967_011.html)

#### Wheat injury symptoms from triallate

Buggy whipping (leaf entrapment)  
Stunted plants  
Leaves emerge from the side of the coleoptile

#### Injury cause

Over-application  
Incorporated too deeply into germinating zone of wheat  
Cool, wet soils



### Additional information and references

Summary of herbicide mechanism of action according to the Weed Science Society of America (WSSA). Available at <http://www.wssa.net/Weeds/Resistance/WSSA-Mechanism-of-Action.pdf>

Wilson, J., J. Nowatzki, and V. Hofman. 2008. Choosing drift-reducing nozzles. FS919. North Dakota Extension Service, SDSU Extension, Brookings, SD. Available at [pubstorage.sdstate.edu/AgBio\\_Publications/articles/FS919.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/FS919.pdf)

Wilson, J. 2006. Calibration of pesticide spraying equipment. FS933. South Dakota State University, SDSU Extension, Brookings, SD. Available at [pubstorage.sdstate.edu/AgBio\\_Publications/articles/FS933.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/FS933.pdf)

Wilson, J. 2002. Pesticide container disposal and recycling. ExEx8078. South Dakota State University, SDSU Extension, Brookings, SD. Available at [pubstorage.sdstate.edu/AgBio\\_Publications/articles/ExEx8078.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/ExEx8078.pdf)

### Acknowledgements

Support for this document was provided by South Dakota State University, South Dakota Wheat Commission, USDA-NIFA, South Dakota 2010 research program. Special thanks to Leon Wrage for many of the images.

---

Clay, S.A. 2012. "Wheat herbicide injury." In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). iGrow Wheat: Best Management Practices for Wheat Production. South Dakota State University, SDSU Extension, Brookings, SD.

*The information in this chapter is provided for educational purposes only. Product trade names have been used for clarity, but reference to trade names does not imply endorsement by South Dakota State University; discrimination is not intended against any product. The reader is urged to exercise caution in making purchases or evaluating product information. Label registrations can change at any time. Thus the recommendations in this chapter may become invalid. The user must read carefully the entire, most recent label and follow all directions and restrictions.*





## CHAPTER TWENTY-SEVEN

# Using Swathing to Accelerate Wheat Drying and Reduce Yield Losses

C. Gregg Carlson ([Gregg.Carlson@sdstate.edu](mailto:Gregg.Carlson@sdstate.edu))

Swathing is a management practice that historically has been conducted to reduce dockage due to weed seed or green kernel contamination. Even though the annual requirement for swathing has been reduced by improved weed control strategies, it can be used to accelerate wheat drying and minimize losses due to sawfly. Videos for swathing wheat are available at <http://www.youtube.com/watch?v=GIbqW6Xhemw>.

### *Swathing wheat*

To reduce yield losses due to insects, weeds, wind, and cool conditions, producers may consider windrowing, or swathing, their wheat. Windrowing is used to accelerate the drying processes under cool conditions. During most South Dakota summers (warm weather), windrowed wheat offers few advantages relative to straight combining, and in many situations, it can even increase the risk of crop loss.

Wheat can be windrowed once it reaches physiological maturity (33 to 43% moisture). At this moisture percentage, the kernel can still be crushed between the thumb and forefinger when squeezed. Because physiological maturity has been reached, windrowing should not influence test weights or protein contents. In order to swath grain, a self-propelled or tractor-assisted swather cuts and windrows the wheat and straw. The grain is then combined at a later date when the grain moisture reaches an acceptable level.

### *Why swath wheat*

If the field contains a substantial variability, it may be desirable to accelerate the drying process. Windrowing can be used to accelerate drying in the late-maturing areas and reduce

losses in early maturing areas. Windrowing will not accelerate the progression of green kernels to ripe kernels. Green immature kernels will remain in the sample after swathing.

Swathing can be used to reduce the weed seeds in the stored grain. Weed seeds can cause storage problems and reduce the quality of the product. Prior to the use of pre-harvest herbicides (Chapter 25), windrowing was the most common method of weed control. It should be pointed out that the use of preharvest herbicides can negatively impact the viability of grain for seed. On the other hand, a preharvest herbicide application can kill weeds, which will reduce the weed seed bank. Additional information about the use of herbicides is available at <http://www.sdstate.edu/sdces/resources/crops/weeds/loader.cfm?csModule=security/getfile&PageID=755002>.

Swathing has been reported to reduce yield losses due to sawfly. Wheat stem sawfly larvae feed inside the stem, which can reduce yields. As the plant senesces, the sawfly moves into the base of the plant, where it cuts the stem. Early swathing can help reduce harvest losses in the current crop. Information for identifying sawfly is available at <http://www.ag.ndsu.edu/pubs/plantsci/pests/e1479.pdf>.

Swathing can be used to reduce lodging, which can occur when the larva cuts the stem. Because sawfly infestations are frequently heaviest on the field border, yield reductions can be reduced by only swathing these areas.

#### Additional information and references

Knodel, J., T. Shanower, and P. Beauzay. 2010. *Integrated pest management of wheat stem sawfly in North Dakota*. E-1479. NDSU Extension Service, North Dakota State University, Fargo, ND. Available at <http://www.ag.ndsu.edu/pubs/plantsci/pests/e1479.pdf>

Winter cereal production, University of Saskatchewan.

Available at [http://www.usask.ca/agriculture/plantsci/winter\\_cereals/index.php](http://www.usask.ca/agriculture/plantsci/winter_cereals/index.php)

#### Acknowledgements

Support for this chapter was provided by South Dakota State University, South Dakota Corn Utilization Council, USDA-NIFA, South Dakota 2010 research program, South Dakota Drought Tolerance Center, South Dakota Wheat Commission, and South Dakota Soybean Board.

---

Carlson, C.G. 2012. Using swathing to accelerate wheat drying and reduce yield losses. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD



## CHAPTER TWENTY-EIGHT

# Minimizing Combine Harvest Losses in Wheat

Daniel Humburg ([Daniel.Humburg@sdsstate.edu](mailto:Daniel.Humburg@sdsstate.edu))

Yield losses can represent the difference between making and losing money. This chapter is intended to provide operators with information needed to minimize harvest losses (Fig. 28.1).



**Figure 28.1.** Examining the concave area and the cleaning shoe in a rotary combine during the wheat harvest.

### *Introduction to harvest losses*

Producers invest time, energy, capital, and management into successfully bringing a crop to maturity. The culmination of this investment is reached at harvest time, which is justifiably hectic and stressful, as producers rush toward the finish line. Careful attention to crop conditions, machine settings, and operator behavior will bring the maximum percentage of the crop out of the field. Conversely, inattention can result in unacceptably large amounts of grain left in the field.

The strong desire to harvest a mature crop can induce producers to rush the process. Minimizing losses requires that time needs to be spent counting kernels on the ground behind the combine and then making the appropriate machine adjustments. Consider that a mere reduction in harvest losses from 4 to 2% in 40-bu/acre wheat will recover an additional 0.8 bushels/acre. At \$7/bushel these adjustments would recover \$896 over a single 160-acre field.

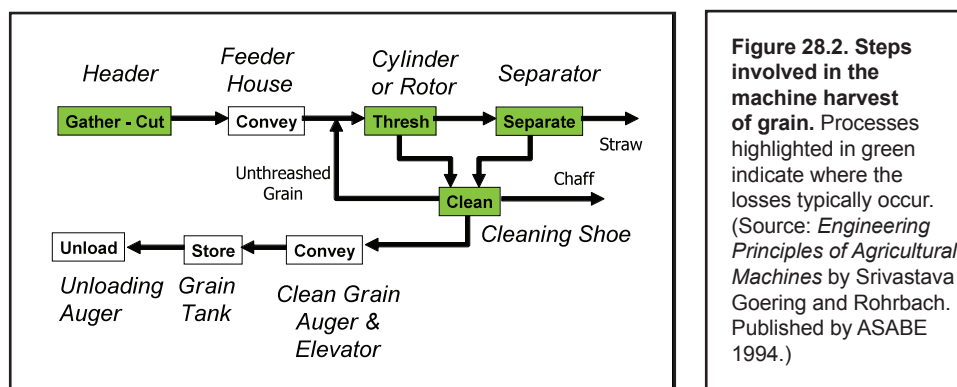
Given today's equipment, it is not possible to completely eliminate harvest losses. Timely and efficient harvests involve striking a balance between the goals of minimizing field losses and rapidly recovering the crop. Properly adjusted combines should have harvest losses that are less than 3%. Losses in excess of 3% may indicate opportunities to adjust the combine and recover more grain.

### Combine processes and losses

An understanding of the processes that take place in the combine is useful prior to making any changes or adjustments to reduce losses. Figure 28.2 represents the combine harvester through its sequence of processing steps. The processes in green are those that normally lead to lost grain. The first process is the cutting, gathering, and transport of the crop that occurs at the combine head.

Research conducted at North Dakota State University has indicated that a large portion of total harvest losses can be attributed to the process of getting the grain into the combine. Table 28.1 shows 63 to 82% of the total losses that occur in wheat harvesting were attributed to shatter and cutter bar losses.

The next process that produces measureable losses is threshing. The grain is freed, or threshed, from the seed head through the action of impact and rubbing at the cylinder or rotor of the combine. Losses here typically occur due to incomplete threshing, where grain is retained in the head, and then passes through the separating and cleaning system and out of the machine. Another form of loss that occurs here is damage to the threshed grain from improper adjustments of the threshing system (namely, 'skinned' and/or broken kernels).



The separator system separates the loose grain from the Material Other than Grain (MOG). In conventional combines, this is accomplished through straw walkers that elevate and accelerate the straw upward, while gravity pulls the grain downward. Rotary machines are able to use larger centrifugal forces to work the grain outward through the mat of straw. Straw is retained inside the threshing and separator cage until it is discharged at the rear of the separator. Losses occur when grain is discharged with the MOG.



The cleaning system uses a shaking action and air blast to lift or blow straw and chaff up and out of the machine. Heavier grain is allowed to pass through the sieves and be collected. Losses occur when the grain is blown out with the chaff. Insufficient air flow may produce a grain sample with high amounts of foreign matter. Excessive foreign matter in the grain (evidenced in the grain hopper) will result in dockage. Material that is too large to pass through the sieves, but too heavy to be blown off, is collected at the tail of the cleaning shoe and recycled for additional threshing. Before looking at each of these processes in more detail, it is essential to determine the level of total harvest losses and to assign them to the part of the machine responsible.

**Table 28.1. Average machine losses in small grains from a study conducted by North Dakota State University.**  
(Source: Vern Hoffman, NDSU)

	1974				1975	
	Hard Red Spring Wheat	Durum	Barley	Oats	Hard Red Spring Wheat	Barley
<b>Shatter and Cutter Bar (Bu/Acre)</b>	<b>0.70</b>	<b>0.66</b>	<b>1.13</b>	<b>0.54</b>	<b>0.98</b>	<b>2.57</b>
<b>% of Total Loss</b>	<b>65%</b>	<b>63%</b>	<b>63%</b>	<b>47%</b>	<b>82%</b>	<b>87%</b>
<b>Cylinder and Separation Loss (Bu/Acre)</b>	<b>0.37</b>	<b>0.39</b>	<b>0.66</b>	<b>0.6</b>	<b>0.21</b>	<b>0.39</b>
<b>% of Total Loss</b>	<b>35%</b>	<b>37%</b>	<b>37%</b>	<b>53%</b>	<b>18%</b>	<b>13%</b>
<b>Total Loss (Bu/Acre)</b>	<b>1.07</b>	<b>1.05</b>	<b>1.79</b>	<b>1.14</b>	<b>1.19</b>	<b>2.96</b>
<b>Crop Yield (Bu/Acre)</b>	<b>21.10</b>	<b>28.20</b>	<b>46.20</b>	<b>48.80</b>	<b>41.70</b>	<b>52.70</b>
<b>% of Crop Lost</b>	<b>4.80%</b>	<b>3.60%</b>	<b>3.70%</b>	<b>2.30%</b>	<b>2.80%</b>	<b>5.30%</b>

### ***Determination of harvest loss***

To reduce harvest losses, a producer must first determine the losses with the current machine settings. Wheat is generally not a difficult crop to harvest, and modern combines are very well adapted to recovering a high percentage of the crop. If a check of losses finds 2% of the yield on the ground, then the producer can smile and continue. However, if losses exceed 3% of total yield, the analysis should continue to identify where the losses are occurring.

A check of machine losses should be conducted any time conditions change that could affect machine performance. Drying conditions as the day progresses will change crop characteristics and the performance of the machine systems. Moving to a new field, with a different variety or maturity, may cause losses from a different machine setting. Checking for losses and making appropriate adjustments is time well spent because:

- The operator will develop a better understanding of the behavior of the machine, and become more adept at fine-tuning it for small variations in condition.
- The amount of grain left on the ground in the field can be minimized.

Once the combine has been adjusted to produce minimal losses, subsequent checks and tuning will not take long. It's a good idea for the operator to take a break, and use this time to count kernels on the ground!

### ***Measuring field harvest losses***

Harvest losses are determined by counting the kernels on the ground behind the combine. This section will discuss methods to determine:

- Pre-harvest losses.
- Losses at the header.
- Losses from the threshing system.
- Losses at the separator.
- Losses from the cleaning system.

Counting twenty (20) to twenty-two (22) kernels of wheat within a one-square-foot area on the ground is equivalent to a loss of one bushel per acre. While this number does depend upon the size of the kernels, 22 will be used in this discussion. To start with, a convenient means of marking a known area on the ground is needed. This can be achieved by creating a square frame of stiff wire or other material with dimensions of 1-foot by 1-foot (1'x1').

Alternatively, a length of stiff wire 42.5" long can be formed into a circle and welded to produce an inside area of 1 ft<sup>2</sup>. Make something that is convenient to use that can be stored in the cab. Now the frame is ready to be periodically used to determine grain kernels on the ground (per square foot) in estimating losses.

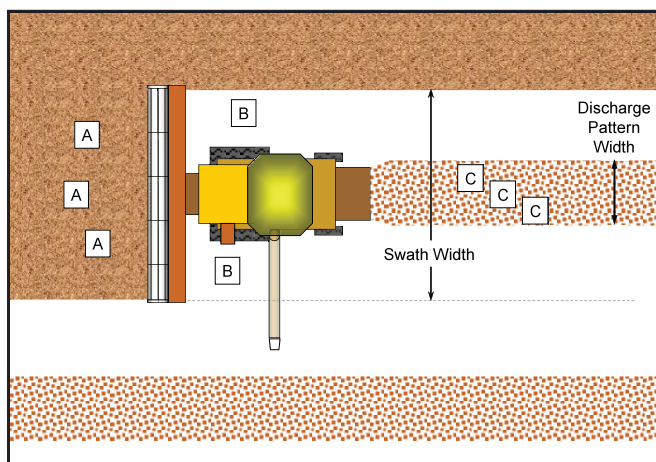
Consistency of observation is important to compare results from one assessment to another. The number of seeds per ft<sup>2</sup> should be made in an area of relatively uniform crop and away from headlands. Take a full swath and operate at constant speed. Stop the machine and the separator; safety is always important. Now use the 1 ft<sup>2</sup> frame to count kernels of grain at locations as indicated in Figure 28.3.

First, check in the standing crop for pre-harvest shatter losses and broken stems in or around the locations marked "A." Determine the average number of kernels in a 1 ft<sup>2</sup> area. If grain is found on the ground, it will not be attributed to the machine settings. This loss cannot be reduced with any amount of machine adjustment, but it is important to measure it so that the machine losses can be accurately separated from pre-harvest losses. Determining losses in swathed wheat and from stripper heads is discussed later.

Next, the grain on the ground behind the header, but forward of the discharge pattern, in areas marked "B," is measured at several locations. This will include counting kernels from heads that were cut or broken from the stem but not recovered by the combine header. Again, determine the average kernel loss in 1 ft<sup>2</sup>. Subtract the kernels/ft<sup>2</sup> of pre-harvest loss from the kernels/ft<sup>2</sup> behind the head to determine losses attributable to the head.

Last, determine the grain loss behind the machine at location "C" in Figure 28.3. Avoid the area immediately behind the machine, particularly if the separator was allowed to empty, and move farther back where the machine was operating steadily. Here it is necessary to determine the width of the distribution of the residue. If no significant spreading is being done, then the width of the discharge is essentially equal in feet to the width of the sieves. If the residue spreader can be easily turned off, it may make it easier to conduct this part of the test. When the combine is distributing the residue wider than the cleaning shoe, these measurements should be done across the residue pattern width.

Determine the width, in feet, of this pattern. Then use the frame to measure losses on the ground in a number of locations within this swath as shown in Figure 28.3. Examine threshed grain heads in these areas for any grain that was not knocked out of the head by the threshing system and record this number for each site.



**Figure 28.3. Locations using grain platform head to determine pre-harvest and machine losses in small grain harvest.**  
(Illustration by Daniel Humburg)

Average the kernel counts at the locations across the discharge pattern to find the number of kernels per ft<sup>2</sup>. Now subtract the combined pre-harvest and header losses (average count at the “B” locations) from the average in the areas marked “C.” This value represents the kernel losses from threshing, separating, and cleaning, but it is concentrated in the residue swath. To distribute these losses evenly across the header swath width, this value is multiplied by the ratio of the residue width divided by header swath width. Now the bushel(s) per acre losses from the machine processes can be determined, as follows:

$$\text{Preharvest loss (bu/acre)} = \text{Average kernels/ft}^2 \text{ in area A} / 22$$

$$\text{Header Loss (bu/acre)} = \text{Average kernels/ft}^2 \text{ in (B - A)} / 22$$

Threshing, Separator, and Cleaning Loss (bu/acre)

$$= \text{Average kernels/ft}^2 \text{ in (C - B)} \times (\text{residue width/header swath width}) / 22$$

Threshing Loss Only (bu/acre)

$$= \text{Average unthreshed kernels/ft}^2 \times (\text{residue width/header swath width}) / 22$$

Total machine losses are equal to the sum of the losses at the head plus losses from threshing, separating, and cleaning. If the combine is equipped with a yield monitor, it may be used to determine the percent losses. Percent machine losses are determined as follows:

$$\text{Percent Machine Loss} = \frac{\text{Machine Loss (bu/acre)}}{\text{Machine Loss (bu/acre)} + \text{Harvested Yield (bu/acre)}} \times 100\%$$

$$\text{Percent Header Loss} = \frac{\text{Header Loss (bu/acre)}}{\text{Machine Loss (bu/acre)} + \text{Harvested Yield (bu/acre)}} \times 100\%$$

$$\text{Percent Separator Loss} = \frac{\text{Separator Loss (bu/acre)}}{\text{Machine Loss (bu/acre)} + \text{Harvested Yield (bu/acre)}} \times 100\%$$

$$\text{Percent Threshing Loss} = \frac{\text{Threshing Loss (bu/acre)}}{\text{Machine Loss (bu/acre)} + \text{Harvested Yield (bu/acre)}} \times 100\%$$

While losses are being measured on the ground behind the combine, it is also worthwhile to look for concentrated losses or leakage. It is not that unusual to produce losses from a loose elevator door, an access panel or a worn auger trough. This might be more visible under the

combine and ahead of the separator discharge pattern. The combine can be backed up after stopping to expose this area without altering the procedure for measuring ground losses as described above.

**Table 28.2. Sample yield loss calculations, part 1.** (Source: Daniel Humburg)

- Wheat is harvested with a 30-foot grain head.
- While operating in a uniform crop area, the operator cuts a 29.5 ft swath.
- The operator adjusts the ground speed to achieve an appropriate load on the threshing and separator systems.
- The combine monitor indicates a yield of 43 bushels per acre.
- Residue is distributed across a pattern that is 12 feet wide.
- After stopping, multiple kernel counts are taken at locations A, B, and C from Figure 28.3.
- Kernels of grain in threshed heads found at C are also counted.
- Table 28.2 illustrates the seed counts and loss calculations from the given example.

**Table 28.2. Sample calculations, part 2.** (Source: Daniel Humburg)

Sample Location	Kernel Counts at Sample Locations					Location Average
	Sample #1	Sample #2	Sample #3	Sample #4	Sample #5	
A	4	6	5			5
B	32	27	28			29
C	38	68	76	69	39	57.8
*C found in heads	*6	*12	*15	*13	*7	*10.6
Preharvest Loss (bu/a)		$5/22 = 0.23$				0.23 bu/acre
Header Loss (bu/a)		$(29 - 5) / 22 = 1.09$				1.09 bu/acre
Threshing Separation & Cleaning Loss (bu/a)		$[(57.8 - 29) \times (12/29.5)] / 22 = 0.53$				0.53 bu/acre
* Threshing Loss (bu/a)		$10.6 \times (12/29.5) / 22 = 0.20$				0.20 bu/acre
Total Machine Loss (bu/a)		$1.09 + 0.53 = 1.62$				1.62 bu/acre
Indicated Yield from combine monitor or measured yield						43 bu/acre
% Machine Loss		$1.62/(43+1.62) \times 100\%$				3.63%
% Header Loss		$1.09/(43+1.62) \times 100\%$				2.44%
% Separator/Cleaning Loss		$(0.53 - 0.20) / (43+1.62) \times 100\%$				0.74%
% Threshing Loss		$0.20 / (43+1.62) \times 100\%$				0.45%

### *Analysis of losses*

Once harvest losses have been measured, the operator must determine if the losses are acceptable and if adjustments are required. A rule of thumb is that losses less than 3% may be acceptable. If crop conditions are good and the harvest is not under extreme time constraints, an operator may wish to tune the machine for losses less than these. In the example given above, total machine losses are 3.63% and some opportunity for improvement exists.

As losses from a combine are identified, adjustments will be made to reduce them. For any type of loss, the operator should consider three contributors to machine performance. First on the list is crop condition. Moisture content is an obvious factor, but other condition factors may also arise. The second contributor is machine settings. Combines have a multitude of these adjustments; learning how they affect performance and how they interact with each other distinguishes a good operator. The last contributor to performance is operator input or behavior.

The most important operator choice is the field speed and its impact on material feed rate into the combine systems. Excessive speed will overwhelm even the best adjustments of machine systems. Similarly, under-loading the machine may lead to losses and/or damaged grain. When losses are measured or analyzed, all three of these contributors should be considered.

### ***Header losses***

In Table 28.2, 67% of the total losses are occurring at the combine head (2.44% header loss / 3.63% total loss). The operator may wish to explore changes to machine settings to reduce this loss. Adjustments that affect header losses include:

- Reel height.
- Cutter/header height.
- Distance forward from the cutter bar to the reel center.
- The reel speed relative to the vehicle speed.

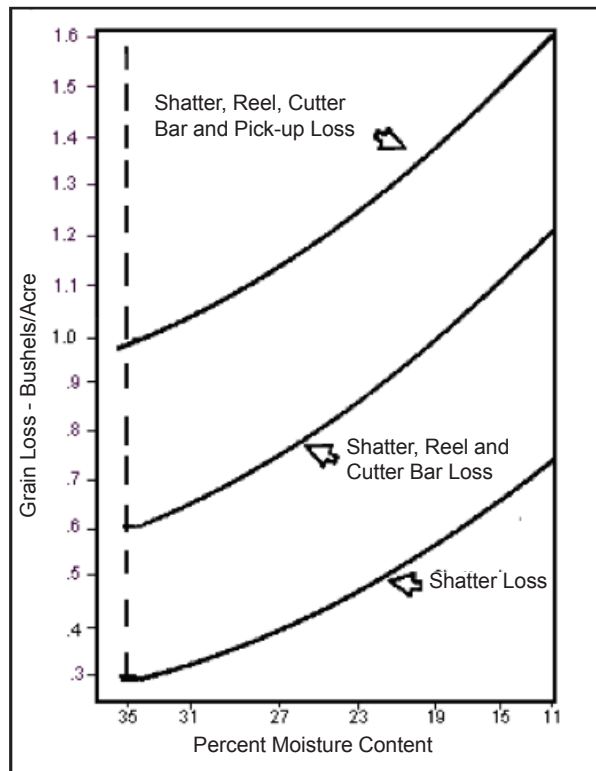
The operator's manual from the manufacturer of the combine and/or head is the best source for the initial settings. If losses at the head are excessive, the manual should be reviewed for appropriate setting and adjustments for the current crop conditions. The condition of the crop at the start of harvest could differ substantially from the condition for which the head was adjusted in the previously harvested crop.

In general, it is wise to make small adjustments and then recheck the losses. Making multiple changes in one step can increase one form of loss, while decreasing another and not reducing the total combine losses. Newer combines have incorporated additional levels of automatic controls and cab-adjustable machine settings. For example, the speed of the reel is normally adjusted to provide a backward velocity of the reel slightly greater than the forward velocity of the machine so that the grain stems are very gently swept backward across the cutter bar.

Many current machines are able to automatically change the reel speed to accommodate an increase or decrease in ground speed. However, the operator can change the ratio of the reel-to-forward speed through the machine settings. Figure 28.4 shows how shatter and cutterbar losses increase dramatically as grain moisture content declines.

Reel speed relationships and other header operational settings should be checked and calibrated at the start of harvest or when excessive losses occur. If previously adjusted for a different crop or for late season conditions, it is wise to reset these settings to the suggested starting conditions for wheat or small grain. From this point, small changes can be used to tune the machine for the current crop.

Cutting height (at the header) is an operator input that can affect header losses, as well as losses in other parts of the system. The combine operates best with a steady flow of crop through it. Header height should be changed as crop height and yield vary in the field to maintain a uniform flow of material through the combine. Changing the cutting height will



**Figure 28.4. Shatter and cutter bar losses with decreasing grain moisture content.** (Source: Vern Hoffman, NDSU)

change the ratio of grain to MOG, which will affect the performance of threshing, separating, and cleaning systems. Crop management may also influence the height setting decision; for example, choosing to bale the wheat straw or managing a no-till operation in a semiarid zone.

### ***Threshing system losses***

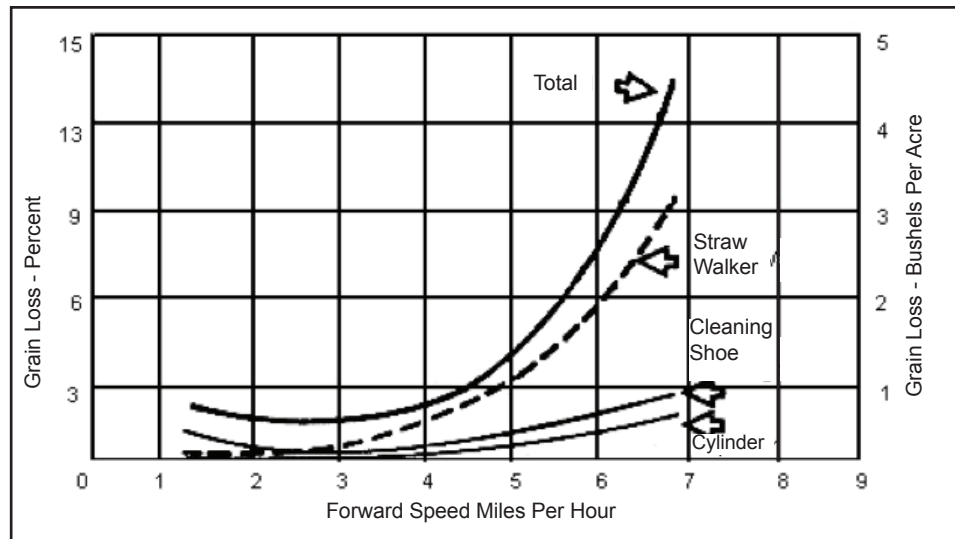
Threshing is accomplished in a combine by a combination of impact and rubbing, which dislodges the grain kernels from the plant head. The efficiency of this process is affected by crop conditions, machine settings, and operational decisions. Crop moisture content is the primary condition factor affecting threshing. Machine settings that affect threshing include the rotor or cylinder speed, the concave type and spacing, and hardware settings that determine the speed of passage of straw through the system.

Operator behavior that most affects the threshing process is the feed rate of material. The crop yield, cutting height, and vehicle speed together combine to determine this flow rate. The relationship between cylinder (threshing) loss and forward vehicle speed (feed rate) is shown in Figure 28.5. Clearly operator decisions here will make a big difference in reducing losses.

Conditions, machine settings, and operator settings interact and it is not possible to specify a perfect combination. Again, the operator's manual for the combine represents the starting point for adjustments for the small grain harvest. As with header adjustments, make small changes to a single setting and then check for the effect by measuring losses. In the example given above, threshing losses were nearly 40% of total machine losses. This might suggest an adjustment to allow less grain, which is still attached to the head, to leave the machine.



Since rotor or cylinder speed, and concave gap, and material flow rate can all affect this loss, it is important to make changes judiciously and then check the result. Also, the changes made to the threshing system can easily affect separation losses, cleaning losses, foreign matter, and damaged kernels as well. Consult your owner's manual for the best order of adjustments for your model combine.



**Figure 28.5. Effect of combine speed on threshing, separating, and cleaning losses in a conventional combine.** While rotary separators may produce different results, the relative trends should follow those shown here. (Source: Vern Hoffman, NDSU)

### *Separator system losses*

As much as 90% of the grain is actually separated at the threshing system under good conditions as threshed grain passes easily through the concave. Loose grain remaining in the straw is then separated by shaking and gravity in a conventional machine, and by centrifugal force in a rotary combine.

Crop conditions, machine settings, and operator choices that affect separation efficiency have much in common with the threshing system. Moisture content, rotor speed, concave gap and material feed rate will affect separation efficiency. However, some changes that increase threshing efficiency will negatively affect separation efficiency. For example, poor threshing may be addressed by narrowing the spacing between rotor/cylinder and the concave or rotor cage.

This change, however, may decrease the separation efficiency as the mat of straw is tighter and more resistant to grain passing through it. It may also increase the amount of damaged grain in a sample.

As with threshing, it is best to begin with the machine settings recommended in the operator's manual for small grains and then adjust one parameter at a time to reduce process losses. In the example analysis above, the losses from separation were less than 1% of harvestable yield and about 12% of the machine losses, which is acceptable. Note again, the relationship between walker (separator) losses and vehicle speed in Figure 28.5.

It is clear that operating at an excessive speed increases material flow rates and can be costly in terms of grain left in the field. The graph shown in Figure 28.5 is derived from test data with only one machine, so results may vary. Some machines may be more forgiving of changes in speed and material flow, but all combines will follow this general relationship.

### ***Cleaning system losses***

Cleaning systems in combines all utilize a combination of air blast to lift off chaff and straw and a shaking action to draw grain downward through the sieves, while moving larger particles to the rear. Again, moisture content of the harvested grain is a crop condition factor that will influence performance. Machine settings that will most affect cleaning system losses include **fan speed** and **sieve opening**.

Fan speed must be sufficient to push through the mat of chaff, straw, and grain on the top sieve and thus carry the lighter material off and out. Insufficient fan speed results in high levels of returns and creates a loop of excessive loading on the sieves. Excessive fan speed will, on the other hand, produce air velocities that can carry grain out of the combine.

As with threshing and separation, the operator controls the feed rate of crop materials, and this can dramatically affect the performance of the system. Insufficient feed rate tends to produce uneven flow of material. Excessive speed can overload the cleaning system, which will lead to heavier flow in the returns and/or cause grain to be passed out with the chaff. The relationship between speed and cleaning losses is illustrated in Figure 28.5.

It is also possible to have material poorly distributed on the sieves, which also leads to losses. If grain and MOG are concentrated in an area of the cleaning shoe, it is possible for the fan air to pass around this concentration and leave part of the shoe overloaded. Higher losses and returns will result. See the “Kill Stall” procedure later in this chapter as a means to diagnose this condition. So-called “slugs” are an example of this situation, though much more prevalent in swathed wheat when bunching has occurred.

The field-test procedure described above lumps separator and cleaning shoe losses into one category. If these losses are found to be excessive, it is helpful to identify the source of the problem. One way to check cleaning system losses is to open the sieves fully and perform another loss test. The fully open sieves will result in high returns, and lots of foreign matter in the sample, but will eliminate the cleaning shoe losses. If this reduces the losses found on the ground then the shoe was the source. If not, the separator was the source of the losses and it should be adjusted.

Follow the manufacturer’s recommendations for making changes to the cleaning system, but make small changes and check the field losses as changes are made.

### ***Monitors***

A trend in combine designs is an ever-greater use of sensors and controls. The ISO communications bus now used in agricultural machinery makes the addition and use of sensor information much easier. Yield monitors are useful for understanding variability in fields, but also simplify the procedure described above for measuring percent losses.

Multiple sensors for grain loss are now designed into the systems for cleaning and separation. These are used to indicate levels of grain loss and are activated by the impact of grain kernels. *While these sensors are valuable as a means of monitoring changes in operation, they should not be treated as a substitute for your eyes/experience.* Rather, once the adjustments are completed for the combine systems and settings to produce low losses for the current crop and conditions, the indicated levels of losses from grain loss monitor on your machine can be safely used. At this point the monitors can be used as an early warning of changes that may occur due to crop conditions, or due to inappropriate loading of the combine. The monitors can help keep the operator and machine systems running with minimal losses at peak machine efficiency.

### ***Kill Stall procedure***

The Kill Stall procedure can be extremely useful in diagnosing combine behavior. The procedure is intended to capture the threshing, separating, and cleaning systems in operation.

To perform the procedure, the machine is operated in uniform representative crop at full header width and at operator-selected ground speed such that the combine separator system is loaded. The combine should be in the highest gear range that allows field operation at this speed. The intention is to stall the engine and this will be easier in high gear. When ready to perform the stall, drop the engine speed setting to the low idle speed, while *simultaneously* pushing the hydrostat, or speed control, to the maximum position, and depressing both brakes. You will want to do this without a full load of grain in the tank!

After the engine stalls, turn off the ignition key. Return the hydrostat to the neutral position. Turn the separator switch and feeder house/header switch to off, and restart the engine to allow it to cool normally, then turn the engine off. This procedure may seem abusive to the machine, but is recommended by some combine manufacturers and can be safely performed. The stall sequence is designed to use the brakes to bring the separator to a rapid halt, rather than having it windmill down as it would if simply disengaged. Don't conduct this procedure if crop conditions are tough (i.e., high moisture), given that restarting the rotor or cylinder would be difficult.

The threshing, separating, and cleaning systems can now be examined to determine much about their operating states. Most new combines provide relatively easy access to these systems, so open any access panels that allow visibility. Examine the distribution of grain and chaff on the chaffer and cleaning sieves.

Overloaded sieves will have excessive grain and chaff left on top. This suggests a lower feed rate, or possibly increasing fan air. The location of the material on the sieves can tell you whether the threshing system is set correctly, or if more material is being processed on one side than the other. Rotary machines will allow shifting of the concave cage to influence the deposition of grain and chaff onto the grain pan. Agitating the material in the threshing/separating system of a rotary combine can indicate its capacity.

Grain found in the straw at the back of the separating system in a rotary machine indicates an overloaded condition and crop flow should be retarded or reduced. Little or no grain in the lower parts of the concave or rotor cage indicates that more capacity exists. Similarly, grain near the top of the straw walkers in a conventional machine indicates system overload, while no grain near the bottom indicates excess capacity. Feed rate may be increased.

Returns and clean grain augers can be examined for the amount and quality of the material. Examine material on the sieves and in the returns to develop a sense for how much straw breakup is occurring with the current settings. The operator's manual and troubleshooting techniques provide guidance on whether the machine is operating as expected or requires adjustment. Following the examination, and noting anything to adjust, all shields and access doors are replaced. Use the manufacturer's recommended procedure for restarting a loaded machine.

### ***Software for understanding interactions between adjustments***

Perhaps the aspect of combine operation and adjustment that is most challenging is the interaction of the many possible adjustments. Few things can be changed on a combine without influencing other things. While it is possible to describe many of these situations, it

is sometimes easier to see the effects graphically. For example, Figure 28.5 shows the effect of forward speed on losses from the cylinder, cleaning shoe, and separator system. Clearly, pushing the machine speed in an attempt to speed the harvest can be counterproductive as losses increase dramatically with excessive loading.

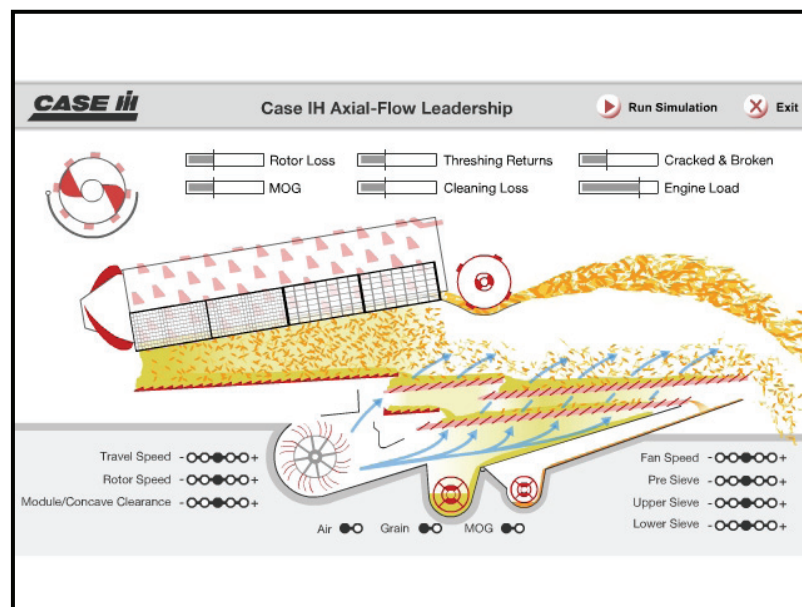
A software application developed by Case IH can be useful for gaining a general understanding of the interaction of machine settings and operator controls on the combine performance. Figure 28.6 shows an image of the rotor, shoe, and fan of an axial flow combine. The program animates the components showing relative motion and the flow of material. At the top of the diagram, graph bars indicate performance measures such as losses, grain damage and engine load. Ideal performance is also indicated by the graphs. Below the machine animation are the machine settings and operator inputs.

The user can interactively increase or decrease any of these settings or inputs. The software will then indicate the likely impact of the change in setting on the six performance measures. In this way it is possible to see which performance measures are impacted by a change to the machine.

The tool is a quick way to consider the impact of a change to the machine or operating point. It may also help identify the unintended consequences of operating at an extreme of one input. The Case IH course on combine theory and settings, along with the dynamic simulator program, can be accessed at <http://cell25.com/CaseIH/htmls/global/course.html>

### Windrowing

Minimizing harvest losses as the crop is cut and gathered will include a careful assessment of the crop condition. Videos for windrowing wheat are available at <http://www.youtube.com/watch?v=GIbqW6Xhemw>. Some producers will have to decide between windrowing wheat (for additional information on windrowing, see Chapter 27) and cutting the crop straight.



**Figure 28.6. Case IH combine simulator illustration.** Changing one or more of the operator adjustments at the bottom is reflected by corresponding changes in the performance measures at the top of the figure. (Source: Case IH website)

The crop condition that will most influence this decision is grain moisture content. Wheat with a moisture < 35% moisture is generally mature. Windrowing wheat when it is between 20% and 35% moisture will minimize shatter losses. Once moisture content falls below 20%, shatter losses from windrowing begin to rise (Figure 28.4), and this may favor allowing the standing grain to dry to storage moisture content followed by straight cutting.

Windrowing can be advantageous where excessive weeds are present, or when the crop has uneven ripening. It may also allow a slightly earlier harvest. Machine settings for the windrower to minimize shatter loss are much the same as for a combine head. The speed of the bottom circle of the reel should be slightly faster than the forward speed of the machine so that the grain stems are gently pushed back onto the cutter bar. Fixed bat reels should be adjusted in height so that the bats contact the crop stems just below the lowest heads of the crop. The centerline of the reel should be 6 to 10 inches ahead of the cutter bar.

The ideal windrow is of uniform depth and with a width equal to that of the feeder house on the combine. The ideal windrow will also have heads distributed evenly across the top of the windrow pointed toward the combine, and with some crisscrossing or weaving of the stems to give it some strength and resistance to settling in places where yields are light and the stubble is thin. Pickup rotational speed is critical to minimizing shatter losses as the dry windrow is taken into the combine.

The windrow should appear to be gently lifted up as the pickup moves underneath it. Excessive pickup speed, relative to combine speed, will begin to pull the windrow apart and strip grain from the heads in the process.

The process of determining losses when combining windrowed wheat is mostly the same as described earlier. It may not be possible to determine pre-harvest losses as any shatter losses occurring at the time of windrowing will also be observed at locations “A” in Figure 28.7. By backing the combine up and measuring losses at locations “B,” it is possible to determine the total of pre-harvest plus windrow and pickup losses. Otherwise, the procedure for determining losses due to the internal parts of the combine is the same.

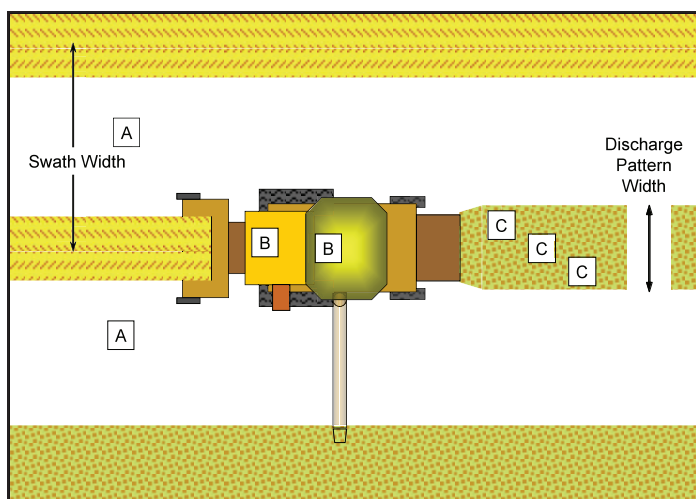
### ***Stripper heads***

Combine stripper heads are effective in small grains, and under some circumstances can recover more grain than conventional heads and machines. Videos using stripper heads are available at <http://www.youtube.com/watch?v=B0yjiD5HdM&feature>, or by searching for Shelbourne CVS Harvesting Wheat.

The stripper head uses a high-speed rotor in the head with a series of stripper plates to remove the grain or grain heads from the straw. The process acts like a comb which leaves most of the straw behind, but traps the heads and forces them off of the stem or to give up the grain within them.

A high proportion of the threshing takes place at the head as the impact of the stripper plates causes much of the grain to be dislodged from the heads at this point. Strippers take in only a fraction of the MOG compared to conventional machines. As a result, the threshing system and separator have a much smaller workload when using a stripper. The cleaning system, however, still must handle the full flow of grain. In fact the cleaning system may be the limiting component in terms of capacity for a combine operating a stripper head.

The process of measuring losses for a stripper head is the same as described earlier for a grain platform head. However, it should be expected that losses on the ground behind the head



**Figure 28.7.** Locations for measuring field losses due to pre-harvest/windrower (A), pickup (B), and threshing, separating, and cleaning (C). (Illustration by Daniel Humburg)

at locations “B” in Figure 28.3 may be higher. Since most of the threshing and separating occurs here, the losses from these processes will be here also. Threshing losses and separating losses from inside the combine are likely to be very small.

The main adjustment to the stripper head is the position of the front hood, which bows the grain stems forward and captures the grain that is pulled upward from the heads. It can be rotated forward or backward. The

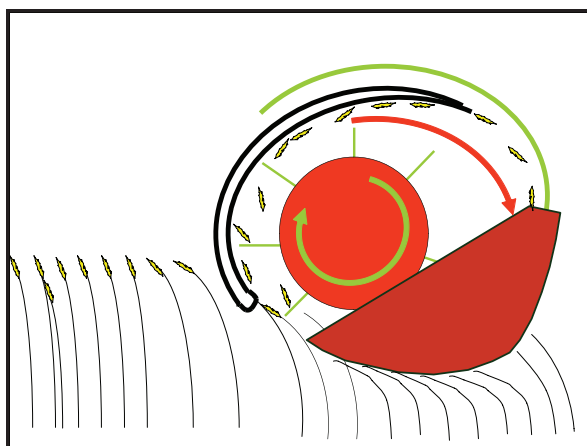
rotor speed is the other principal machine setting. Operator controls include the height of the head above the ground and the forward speed. Speed with stripper heads is much higher than with conventional heads, and they seem to work better at relatively high speed. As with conventional heads, the operator’s manual will have guidelines for adjustments to minimize losses and accommodate varying crop conditions.

Stripper heads have several advantages. First, since little straw enters the combine, the condition of the straw is not a factor and the machine is not troubled by tough, or damp, straw. Second, the crop can be harvested as soon as the heads and grain reach an acceptable moisture content. Third, strippers excel at recovering lodged grain.

A video clip of a Shelbourne head taking lodged wheat can be viewed at <http://www.youtube.com/watch?v=cDV1aE0uuPo&feature>.

The combs or stripper plates are able to rake lodged straw and capture heads from near the ground that are inaccessible to a conventional cutter bar and reel. However, stripper heads may not be as applicable in rough terrain where high vehicle operating speeds would be unacceptable.

### Summary



**Figure 28.8. The stripper head concept.** Straw is left in the field and grain heads are combed from the straw and captured under a hood onto the header platform. (Illustration by Daniel Humburg)



Growers interested in minimizing their harvest losses can do so by taking the time to measure the losses in the field. When grain losses are too high, the inefficient processes can be identified through careful analyses, and machine adjustments can be made to reduce these losses. Harvest loss tests should be done at the start of harvest and when changing from one crop to another, or when conditions change substantially.

Performing test like the Kill Stall can also build a better understanding of the interaction of machine settings with each other and with crop conditions. Once the combine is appropriately adjusted, it may only require occasional checks of losses. Also, upon achieving a well-tuned combine, the loss monitors can help identify when conditions change sufficiently so that another check of losses and their sources should be conducted. Minimizing losses is well worth the time spent as most producers have a goal to harvest the most wheat possible in a field rather than finish the quickest (see Harvest Loss Check Form on next page).

#### Additional information and references

Case IH. 2010. CASE IH axial flow combine operator's manual. 3rd Edition, Print No. 84298546. CNH America LLC. Manuals can be purchased at Case IH dealerships.

Case IH. 2010. Theory of combine settings and adjustments.  
Available at <http://cell25.com/CaseIH/htmls/global/course.html>

Hoffman, V. 1978. Grain harvest losses. Minnesota Association of Wheat Growers.  
Available at <http://www.smallgrains.org/Techfile/Sept78.htm>

Sumner, P.E., and E.J. Williams. 2009. Measuring field losses from grain combines. Bulletin 973. University of Georgia Cooperative Extension Service. Available at [http://www.caes.uga.edu/publications/pubDetail.cfm?pk\\_id=6115](http://www.caes.uga.edu/publications/pubDetail.cfm?pk_id=6115)

#### Acknowledgements

Support provided by the South Dakota Agricultural Experiment Station.

---

Humburg, D. 2012. Minimizing combine harvest losses in wheat. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). iGrow Wheat: Best Management Practices for Wheat Production. South Dakota State University, SDSU Extension, Brookings, SD.

## Harvest Loss Check Form for Wheat

Field Identification: \_\_\_\_\_

Variety: \_\_\_\_\_

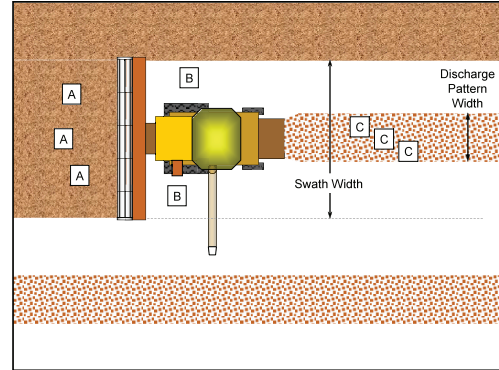
Condition of crop: \_\_\_\_\_

Concave setting: \_\_\_\_\_

Rotor Speed: \_\_\_\_\_

Fan Speed: \_\_\_\_\_

Combine forward speed: \_\_\_\_\_



### Other machine settings

Swath or header width \_\_\_\_\_  $W_{\text{swath}}$

Discharge pattern width \_\_\_\_\_  $W_{\text{residue}}$

### Kernel Counts Per Square Foot at Sample Locations

Sample Location	Sample #1	Sample #2	Sample #3	Sample #4	Sample #5	Average at Location
A						=A <sub>avg</sub>
B						=B <sub>avg</sub>
C						=C <sub>avg</sub>
*C found in heads						=C* <sub>avg</sub>
Pre-harvest Loss (bu/a)		$A_{\text{avg}} / 22$				
Header Loss (bu /acre)		$(B_{\text{avg}} - A_{\text{avg}}) / 22$				=H <sub>L</sub>
Threshing Separation & Cleaning Loss (bu/acre)		$[(C_{\text{avg}} - B_{\text{avg}}) \times W_{\text{residue}} / W_{\text{swath}}] / 22$				=TSC <sub>L</sub>
* Threshing Loss (bu/a)		$(C*_{\text{avg}} \times W_{\text{residue}} / W_{\text{swath}}) / 22$				=T <sub>L</sub>
Total Machine Loss (bu/a)		$H_L + TSC_L$				=M <sub>L</sub>
Indicated Yield from combine monitor or measured yield						=Y
% Machine Loss		$M_L / (M_L + Y) \times 100\%$				
% Header Loss		$H_L / (M_L + Y) \times 100\%$				
% Separator/Cleaning Loss		$(M_L - T_L) / (M_L + Y) \times 100\%$				
% Threshing Loss		$T_L / (M_L + Y) \times 100\%$				

Grain Damage \_\_\_\_\_ Straw condition \_\_\_\_\_

Foreign Matter \_\_\_\_\_



## CHAPTER TWENTY-NINE

# Estimating Wheat Yield Potentials

David E. Clay ([David.Clay@sdstate.edu](mailto:David.Clay@sdstate.edu))

C. Gregg Carlson ([Gregg.Carlson@sdstate.edu](mailto:Gregg.Carlson@sdstate.edu))

Yield estimates can be used for a variety of purposes ranging from determining how much N to apply to estimating the amount of grain available for marketing. This chapter discusses several techniques for estimating wheat yields.

### Rules of Thumb in Estimating Yields

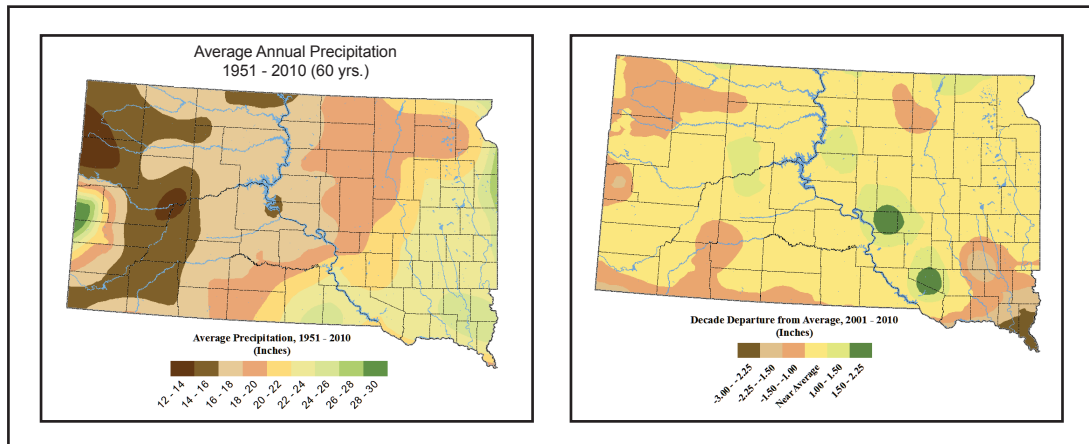
- Yield estimates need to be continuously updated based on information obtained during field scouting (Chapter 21).
- Initial estimates are based on long-term weather averages and previous yields.
- In-season estimates are based on measured plant and/or heads/acre.
- Examples for all calculations are provided.

Yield estimates can be used for estimating nutrient removal, determining fertilizer recommendations, making replanting decisions, and developing pest management recommendations. When estimating yield, it is important to remember that the predictions are only as good as the information collected.

### *Factors influencing yield variability*

In South Dakota, yields are influenced by water and temperature variability. Estimating yield potentials would be easy if we always had average temperatures and precipitation (Fig. 29.1). However, in South Dakota, average climatic conditions are the exception from the norm. Tracking the crop yield potential is one approach to help manage this variability.

**Figure 29.1. Average rainfall from 1951-2010 and rainfall from 2000-2010**



**Table 29.1. Methods for estimating yield goal.**

<http://www.extension.iastate.edu/Publications/PM1268.pdf>

- Remote Sensing.
- Field History (Field).
- Yield goal +, Add 10% to a multiple year average where the maximum and minimum values have been removed.
- Yield goal + moisture, Adjust a multiple-year yield, after outliers have been removed, based on plant available water.
- County Average.
- Productivity Index.

### ***Estimating preplanting yield potential***

Preplant yield potentials can be estimated using remote sensing or averaged from prior yield records (Table 29.1; Chapter 16; Reitsma et al. 2011). Prior yield records are used to determine the field average. In this calculation, the outliers are removed from the data set. There are many modification of this basic method. For example, the average value can be increased or decreased 10% based on soil moisture (Table 29.2).

### ***Estimating winter wheat yields prior to tillering and stem elongation***

Wheat yield estimates prior to tillering can be used for replanting decisions and determining in-season N application rates (Chapters 11, 15). These calculations are based on several assumptions. *First*, soil moisture, nutrients, and diseases will have minimum impact on yields. *Second*, each

**Table 29.2. An example showing how a wheat yield goal is determined from multiple years of data.**

#### *Field records*

Year	Yield (bu/A)	Conditions
1	40	Poor
2	40	Average
3	50	Average
4	47	Average
5	52	Average
6	45	Poor
7	48	Average
8	63	Excellent
9	61	Excellent
10	53	Average
Potential	*52	*Average

#### *\*Predicted Values*

The yield goal + moisture recommendation would be:

Full soil profile

$$52 + 0.10 \cdot 52 = 57 \text{ bushels}$$

Average soil profile

$$52 \text{ bushels}$$

Poor moisture conditions

$$52 - 0.10 \cdot 52 = 47 \text{ bushels}$$

*For this approach a producer should be prepared to add additional fertilizer if needed.*

plant produces 5 heads and each head contains 22 kernels. *Third*, a bushel of wheat at 13.5% moisture weights 60 lbs and a pound of wheat contains 16,000 kernels.

It is important to point out that in many situations, tillering decreases with increasing planting rate and the head per plant, and tillers per head can be impacted by planting date. Table 29.3 shows the calculations needed for this estimation, while Table 29.4 provides information for various plant distributions.

**Table 29.3. Estimating yield potential prior to tillering.**

1. Count the number of plants per foot of row.
  - a. Measure plants in 5 feet of row in at least 5 locations.
  - b. These locations should represent the field conditions.
2. Measure the distance between the rows.
3. Calculate the yield potential.

$$\frac{\text{bu}}{\text{acre}} = \frac{\text{plant}}{\text{ft row} \times (\text{row width in inches}) \times \frac{1 \text{ ft}}{12 \text{ inches}}} \times \frac{\# \text{ heads}}{\text{plant}} \times \frac{\# \text{ kernels}}{\text{head}} \times \frac{\text{lb}}{16,000 \text{ kernels}} \times \frac{\text{bu}}{60 \text{ lbs}} \times \frac{43,560 \text{ ft}^2}{\text{acre}}$$

$$\frac{\text{bu}}{\text{acre}} = \frac{\text{plants}}{\text{ft row} \times (\text{row width in inches}) \times \frac{1 \text{ ft}}{12 \text{ inches}}} \times \frac{5 \text{ heads}}{\text{plant}} \times \frac{22 \text{ kernels}}{\text{head}} \times \frac{\text{lb}}{16,000 \text{ kernels}} \times \frac{\text{bu}}{60 \text{ lbs}} \times \frac{43,560 \text{ ft}^2}{\text{acre}}$$

$$\frac{\text{bu}}{\text{acre}} = \frac{\text{plants}}{\text{ft row} \times (\text{row width in inches}) \times \frac{1 \text{ ft}}{12 \text{ inches}}} \times \frac{5 \text{ bu} \times \text{ft}^2}{\text{plant} \times \text{acre}}$$

Example: If a wheat field contains contained 5 plants/foot and the row spacing is 7.5 inches, what is the yield potential?

$$\frac{\text{bu}}{\text{acre}} = \frac{5 \text{ plant}}{\text{ft row} \times 7.5 \text{ inches} \times \frac{1 \text{ ft}}{12 \text{ inches}}} \times \left( \frac{5 \text{ bu} \times \text{ft}^2}{\text{plant} \times \text{acre}} \right) = \frac{25 \text{ bu}}{0.625 \text{ acre}} = \frac{40 \text{ bu}}{\text{acre}}$$

**Table 29.4. Winter wheat yields can also be estimated from the table below.**  
(Modified from Lyon and Klein 2007)

Row Spacing (inches)	Plants/foot row				
	1	3	5	7	9
6	10	30	50	70	90
7.5	8	24	40	56	72
10	6	18	30	42	54
14	4	13	22	30	39

### ***Estimating spring wheat yields prior to tillering and stem elongation***

Spring wheat yield estimates prior to tillering requires a small adjustment. The number of heads per plant is slightly lower in spring than winter wheat. Hanson (2001) reported that in North Dakota, 4.6 heads per plant are produced when wheat is planted at 0.5 million seeds/acre and 2.1 heads per plant are produced when planted at 2 million seeds per acre. He also reported that the number of kernels per head is impacted by population. For a population of 0.5 million seeds/acre, each head contained 25 kernels and for a population of 2 million seeds per acre, each head contained 20 kernels.

### Yield estimates for winter and spring wheat near maturity

Yield estimates near maturity are used for harvest planning and marketing decisions. In the following calculations we will make two assumptions, a pound of wheat contains 16,000 kernels and a bushel of wheat at 13.5% moisture weighs 60 lbs. In these calculations, it is important to remember that 1 acre = 43,560 ft<sup>2</sup>.

To estimate yield, the number of kernels per head, heads per foot of row, and row spacing must be measured (Table 29.5). Accuracy is improved by increasing the sampling size, or the number of locations where the counts are made. Guidelines for these calculations are that the number of head in a foot of row should be measured in at least five locations. Count the number of kernel per head in at least five heads per location. Because the head size diminishes on tillers, the kernel counts should be made on both main and tiller heads. Sample calculations are below.

**Table 29.5. Estimating yield in a crop nearing maturity.**

$$\frac{\text{bu}}{\text{acre}} = \frac{\# \text{ heads}}{\text{ft row} \times (\text{row width in inches}) \times \frac{1 \text{ ft}}{12 \text{ inches}}} \cdot \frac{\# \text{ kernels}}{\text{head}} \cdot \frac{\text{lb}}{16,000 \text{ kernels}} \cdot \frac{\text{bu}}{60 \text{ lbs}} \cdot \frac{43,560 \text{ ft}^2}{\text{acre}}$$

$$\frac{\text{bu}}{\text{acre}} = \frac{\# \text{ heads}}{\text{ft row} \times (\text{row width in inches}) \times \frac{1 \text{ ft}}{12 \text{ inches}}} \cdot \frac{\# \text{ kernels}}{\text{head}} \cdot \frac{0.5445}{\text{row}(\text{inches})}$$

Example : If a wheat field contains contained 30 heads/ft and 22 kernels/head, what is the yield estimate if the row spacing is 7.5 inches?

$$\frac{\text{bu}}{\text{acre}} = \frac{30 \text{ heads}}{\text{ft row}} \times \frac{22 \text{ kernels}}{\text{head}} \times \frac{0.5445}{7.5} = 51.3 \text{ bu/acre}$$

#### Additional information and references

Hanson, B. 2001. *Planting rate influence on yield and agronomic traits of hard red spring wheat in northeastern North Dakota*. NDSU Ag Report. NDSU, North Dakota Experiment Station.  
Available at <http://www.ag.ndsu.nodak.edu/aginfo/agreport/ar1w.htm>

Lyon, D.J., and R.N. Klein. 2007. *Estimating winter wheat yields*. Neb Guide G1429. University of Nebraska-Lincoln Extension, Institute of Agriculture and Natural Resources.  
Available at <http://elkhorn.unl.edu/epublic/live/g1429/build/g1429.pdf>

Reitsma, K.D., R.K. Heimerl, and T.E. Schumacher. 2011. *Estimating soil productivity and energy efficiency using the USDA Web Soil Survey, soil productivity index calculator, and biofuel energy system simulator*. In Clay D.E. and J.F. Shanahan. (eds.) *GIS Applications in Agriculture: Nutrient Management for Energy Efficiency*. Volume 2. CRC Press and NC SARE. New York, NY.

#### Acknowledgements

Support was provided by South Dakota Wheat Council, South Dakota Drought Tolerance Center, USDA-AFRI, and the South Dakota Agricultural Experiment Station.

Clay, D.E., and C.G. Carlson. 2012. Estimating wheat yield potentials. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.





## CHAPTER THIRTY

# Quality Traits and End-Use Functionality of South Dakota Hard Red Spring and Hard Red Winter Wheat

*Padmanaban G. Krishnan* ([Padmanaban.Krishnan@sdstate.edu](mailto:Padmanaban.Krishnan@sdstate.edu))

*Julie Darly* ([Julie.Darly@sdstate.edu](mailto:Julie.Darly@sdstate.edu))

*William Berzonsky* ([William.Berzonsky@sdstate.edu](mailto:William.Berzonsky@sdstate.edu))

*Karl D. Glover* ([Karl.Glover@sdstate.edu](mailto:Karl.Glover@sdstate.edu))

Wheat can be made into products ranging from noodles to cake flour. Each product requires wheat with different characteristics (Fig. 30.1). Interactions between genetics, management, and climatic conditions impact the ability to produce wheat with specific characteristics. The purpose of this chapter is to discuss these factors and the importance of considering end-use quality in management decisions.



**Figure 30.1. Bread loaf volume as a function of flour protein content and gluten strength.** (Photo by P.G. Krishnan, SDSU Crop Quality Lab)

### Wheat Quality Observations

1. The selling and purchasing price of wheat is influenced by moisture and protein percentage. Wheat protein is reported on the 12% moisture basis. The protein basis for hard spring red wheat is generally 14%.
2. Grain protein is often influenced by water and nitrogen availability along with grain filling during the growing season. Low grain protein may be associated with high wheat yields. Both protein content and protein quality influence the quality of end-use food products.
3. Management, climate, and genetics interact to influence grain quality and, ultimately, the quality of the flour milled from the wheat. Carefully designed longitudinal studies provide baseline information on quality parameters that permit decision-making on end-use efficacy of South Dakota wheat varieties. This baseline information is helpful in detecting sudden shifts in quality and in the devising of practical solutions for the wheat production and processing industry.
4. Grain quality is more than test weight and protein content. Advanced instruments and analytical capability now exist in the Crop Quality Lab at SDSU to assist the wheat breeders in developing value-added traits in our wheat.
5. Split nitrogen application can be used to improve protein content and reduce lodging.
6. Baseline wheat quality data is provided in this chapter.

### Introduction

Wheat quality is evaluated using many different measurements. Table 30.1 provides a summary of physical properties (test weight, damaged kernels, foreign materials, shrunken and broken kernels, kernel weight and hardness) and dough performance tests (stability and peak mixing time). The kernel traits provide information on how the wheat will perform in processing (milling, baking, pasta extrusion, noodle production, etc.) and its suitability for different end uses.

For the purpose of the discussion, data provided in this table reflect real world information derived from 314 samples from the Winter Wheat Breeding Program and Spring Wheat Breeding Program grown over three crop years (2006-2009) in diverse growing locations. Replications over time and locations, therefore, lend a high degree of reliability to observations and conclusions. Furthermore, the data pertain to South Dakota wheat grown in South Dakota locations.

In determining end-use quality, the important factors are wheat kernel, the flour milled from the wheat, the dough produced using the flour, and finally, the finished product made with the dough. Each finished product has its own unique quality characteristics, i.e., wheat used to produce tortillas has different characteristics than the wheat used to produce Asian noodles.

A quality evaluation program linked to breeding and crop production programs is used to monitor key traits, develop new cultivars, and design management practices that produce flour that meets or exceeds specified standards (Table 30.1).

**Table 30.1. Wheat quality measures, definitions, and impact on the milling process.**  
(Modified from Regnier et al. 2009)

Characteristic	Definition	Effect on Wheat Milling
Test weight	Bulk density, weight of a specified volume	Provides estimate of flour yield
Damaged kernels	Kernel defects due to heat, insects, frost, sprouting, and scab	Impacts appearance, decreases yield and increases ash
Foreign materials	All non-wheat materials	Must be removed prior to milling
Shrunken and broken kernels	Pass through a #2 sieve in a Carter Day Dockage Tester	
Moisture	Percentage of wheat that is water	Moisture and test weights have an inverse relationship
Protein	Percentage of wheat that is protein (nitrogen)	Impacts textures and bread quality
Kernel hardness	Average texture, can be hard or soft	Hardness impacts energy required to mill to flour
Kernel weight	Weight of individual kernels	
Kernel diameter	Diameter of individual kernels	Impacts ease of milling
Flour yield	Percentage of flour recovered during milling	Impacts economics
Falling number	Indicator of sprout damage and flour's ability to set up	Value > 250 indicates gummy bread and flour will be unable to thicken soups
Gluten	High protein food product directly related to protein content	Impact dough strength, gas retention, water adsorption, and flavor
Ash content	Inorganic material contained in the grain, does not burn	Impacts flour color and quality
Peak mixing time	Time required for the flour to reach full development	Optimum mixing time
Stability	Time difference between the arrival and departure times	Ability to adjust to over- and under-mixing
Absorption rate	Amount of water to reach maximum consistency	Optimum use of water
Tenacity (P)	Peak height, maximum pressure required to produce a bubble	High P value is light and fluffy
Extensibility (L)	How long until it take until the bubble bursts	Impacts dough ability to rise
Strength (W)	Baking strength of dough	High value high dough strength
Configuration ratio (P/L)	Resistance related to time, indicator of gluten behavior	Bread volume and well proportioned inside structure
Internal characteristics	Crumb quality (texture, color, and shape)	Impacts end-use qualities
Bread-loaf volume	Bread making potential	Impacts amount of bread produced

### ***Wheat quality, protein content***

Gluten proteins make up about 78 to 85% of the total wheat protein. Gluten is not a physical entity that initially exists in wheat; rather, it develops only when water is added to the physical mixing of the proteins.

Gluten can be divided into the soluble gliadins and the insoluble glutenins. Gliadins confer viscous flow, whereas, glutenins confer elasticity (Shewry and Tatham 1997). Gliadins impact dough viscosity and are primarily monomeric molecules with molecular weights ranging from 28,000 to 55,000. High temperatures during grain filling can result in wheat with a high gliadin concentration (Blumental et al. 1991).

On the other hand, glutenins are aggregated proteins linked by disulphide bonds. Glutenin subunits have been separated into high molecular weight (67,000-88,000) low in sulfur, and low molecular weight (32,000-35,000) subunits high in sulfur. Approximately 20% of glutenin is high molecular subunits and 80% of glutenin is low molecular subunits. The relative amounts of gliadin and glutenin impact dough firmness, strength, and elastic behavior (Hamada et al. 1982).

Depending upon the protein composition, two samples with identical protein content can vary with regard to baking potential. Protein composition is related to the ability of gluten to stretch and to hold the gasses produced in yeast fermentation. Ideal bread production requires both adequate CO<sub>2</sub> production as well as the ideal gas retention capacity of the gluten superstructure. The absence of either would result in poor loaf volume.

The mixing properties of dough are measured with specialized instruments, such as Farinograph® or Mixolab®. These instruments measure dough viscosity, which is related to dough strength. The information obtained from these two instruments is: 1) correlated to each other, and 2) provide data needed to formulate new recipes and assess the potential impact of gluten or wheat protein isolate additives on performance.

Based on quality characteristics, it is now possible to profile various flours for specific food products (cookies, crackers, pizza crust, cakes, etc). Manufacturers often write tight specifications based on these instrument-derived parameters.

### ***Wheat for different end uses***

Wheat flour can be used for different end uses. Wheat flour that produces large loaves and has high water absorption capacities has an economic advantage over those flours that do not. Table 30.2 shows the differences in gluten content in All Purpose Flour (APF), bread flour and cake flour.

The moderate amount of protein (and gluten) in All Purpose Flour permits the home baker to use the flour in a variety of baked products. Breads, on the other hand, demand stronger gluten to withstand the additional stresses of dough mixing, dough stretching and expansion during yeast fermentation. The type of flour used impacts the resulting bread (Fig. 30.1). Bread machines will often require higher protein and gluten content as the machines may be mechanically physically abusive to dough systems. Commercial flours are blended to yield high gluten content and a gluten index, which is measured with a Glutomatic System. <http://www.sdsinstruments.com/glutomatic.asp>

In this analysis, flour is mixed with water to form dough and then the dough is washed to remove the milky starch slurry. The resultant putty-like material is known as wet gluten, or vital gluten. The wet gluten is weighed and then excess water is spun out of the dough in a centrifuge. The dough is then formed into a disk and dried in a heated press; the resulting dry gluten is weighed. The centrifugal force also is capable of separating wet gluten into two gluten fractions. The wet gluten is subjected to forces that allow some of the gluten to penetrate openings in a sieve.

The weights of the wet gluten, gluten fractions, and dry gluten are correlated to other flour physical traits to relate protein content to protein functionality. Figure 30.2 shows pictures of strong and weak glutes taken through the gluten test. Weaker gluten blends have a greater proportion of the wet gluten moving through the wire mesh (far right image in Fig. 30.2).

The gluten index value defines whether the gluten is weak, strong or normal. If the gluten is very weak, the index value will be near 0, whereas if it is very strong, it will be near 100%. Commercial flours are formulated with ingredients for high gluten index (Table 30.2).

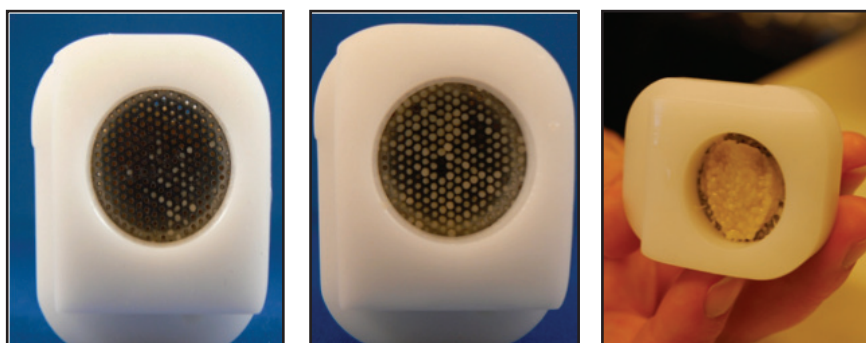
**Table 30.2. Gluten Content and Gluten Index measurement of various flours.**  
Breads produced with these flours are shown in Figure 30.1.

Sample	Total Gluten <sup>1</sup> (g)	Dry Gluten <sup>2</sup> (g)	Gluten Index <sup>3</sup>	% Gluten	Mean
All Purpose Flour	2.37	0.86	100	8.6	8.6
	2.38	0.86	100	8.6	
Bread flour	2.43	0.87	100	8.7	8.7
	2.44	0.87	100	8.7	
Cake flour	1.95	0.71	100	7.1	7
	1.93	0.69	100	6.9	

1 Total Gluten: Weight of gluten extracted from 10 grams flour.

2 Dry Gluten: Dry weight of above.

3 Gluten Index: The relative amount of of gluten (weaker gluten) that comes through a specially designed sieve under centrifugation. 100% GI indicates no weaker gluten penetrating the sieve.



**Figure 30.2. Gluten fractions obtained from gluten testing of Glenn (left) and Briggs (middle) varieties.** Image on the far right shows extremely weak gluten penetrating the Glutomatic sieve. (Photo by P.D. Krishnan, SDSU Crop Quality Lab)

### Gluten quality and end use

Two samples with identical protein contents can vary significantly with regard to baking potential. Protein quality is related to the ability of gluten to stretch and to hold the gasses produced in yeast fermentation. Ideal bread production requires both adequate CO<sub>2</sub> production as well as the ideal gas retention capacity of the gluten superstructure. The absence of either results in poor loaf volume.

Dough viscosity will rise and fall with mixing and this is often related to how the dough responds to mixing or over-mixing. Instruments such as the Farinograph and Mixolab are used to make these measurements as well as reveal how flour and dough will react to ingredient changes. Dough additives, such as vital gluten or wheat protein isolates and concentrates, can improve the performance of weaker flours.

No single wheat quality measurement by itself is sensitive enough to discriminate between good and poor baking potential (Table 30.3). Hence, a more comprehensive set

of parameters is used in a quality evaluation program. Relative values of the gluten index need to be interpreted along with other dough functional properties, such as absorption percentage, dough development time, dough stability, along with dough strength and dough extensibility information provided by the Texture Analyzer Kieffer Rig. It is a combination of instrument-based data that allows for definitive judgments to be made about the performance efficacy of single wheat varieties.

**Table 30.3. Comparison of wheat varieties showing variability in flour water adsorption (WA), development time, stability, gluten index, dry gluten, dough extensibility, and dough strength.** Highlighted values below indicate a trend toward lower values for the parameters indicated. (Daryl, J. personal communications, South Dakota State University, 2011)

Year	Variety	WA <sup>1</sup> (%)	Development Time <sup>2</sup> (min)	Stability <sup>3</sup> (min)	Gluten Index (%)	Dry Gluten (g)	Dough Extensibility (mm)	Dough Strength (g)
2008	AC Snowbird	58.5	8.0	11.0	98.5%	1.46	39.6	51.5
	Alpine	59.6	8.5	11.6	99.4%	1.30	25.1	79.0
	Briggs	63.5	8.7	9.4	97.6%	1.49	26.6	51.5
	Glenn	59.8	9.4	11.0	99.7%	1.51	28.4	81.0
	Lolo	54.6	7.6	11.4	99.1%	1.21	47.1	39.8
2009	AC Snowbird	62.1	8.8	10.9	97.8%	1.26	64.6	32.5
	Alpine	62.7	8.8	12.1	98.3%	1.22	85.8	31.0
	Briggs	59.9	6.1	11.1	96.5%	1.20	71.1	27.5
	Glenn	61.3	9.3	11.9	99.0%	1.27	86.4	39.1
	Lolo	59.0	8.1	11.4	97.8%	1.14	72.3	33.4

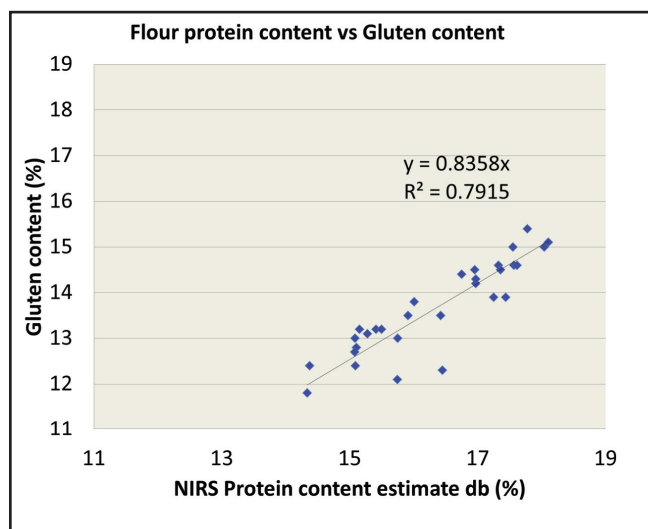
- 1 Water absorption is defined as the ideal amount of water to be added to flour to form an optimal dough (as determined by the instrument).
- 2 Dough Development Time is the time in minutes required to reach peak mixing time.
- 3 Dough Stability provides an indication of the duration of mixing time when the dough remains stable before breaking down. Dough protein is a biological entity and will denature and lose its cohesive properties with over-mixing and mechanical abuse.

Instruments such as the Mixolab or Farinograph yield crucial information on the amount of energy inputs and water requirement for production of an optimal dough. In this analysis, 30 to 50 grams of flour are needed. As water is added to and mixed with flour, dough is formed. The dough increases in viscosity and offers resistance to the mixing blades. This resistance is translated into a visual graph plotting torque against the mixing time. The resulting output reveals how stable the dough is to over mixing, optimal mixing times, and optimal water requirement. It also expresses the changes that occur as a result of addition of other ingredients normally used in baking. This information can be physically or electronically linked to flour shipments to provide visual documentation specific to the particular sample.

In many situations, information derived from one test is correlated to information derived from other tests. For example, water absorption by the flour (to yield optimal dough) is strongly related to the gluten proteins (Fig. 30.3). This is an important functionality of protein. About 80% of the variability in gluten content is explained by the protein content in the wheat flour. The proteins contribute to the expansion of the dough to envelope the



expanding gasses (steam, CO<sub>2</sub>) and also the ability to retain the gases. While this relationship between flour protein and flour gluten content is strong and well documented, the relationship between flour protein (a flour constituent) and loaf volume (a functional trait) is strong in some years and weak in others.



**Figure 30.3. Relationship between flour protein and gluten content in 2008 HRS Selby wheat.** (Data from Caffè-Treml et. al 2010b)

#### *Wheat quality, climate and management*

Nitrogen and water management interact to influence wheat production and quality (Table 30.4). For example, applying more N fertilizer to increase yields and protein content can increase lodging. One approach to overcome this problem is to split the N application (Chapters 8 and 9). Fuertes Mendizábal et al. (2010) reported that splitting N applications from a single pre-plant rate into several split applications improved grain quality and the concentration of high molecular weight glutenin subunits.

In South Dakota, research highlighted in Table 30.4 shows that yield and wheat quality were both impacted by N rate and that each characteristic has a unique optimum N rate (Kharel et al. 2011; Reese 2009). Currently, active research projects are being conducted to improve in-season N recommendations.

**Table 30.4. The influence of N rate on hard white winter yield and quality in 2008 at Dakota Lakes Research Farm.** (Kharel et al. 2011)

% Recommended N rate	Yield	Protein	Stability	Nitrogen Use Efficiency
	<i>bu/a</i>	<i>%</i>	<i>min</i>	<i>%</i>
0	66.8	11.7	8.2	
25	75.3	12.3	8.3	46
50	75.1	12.7	10	27
100	82.3	13.2	10.3	26
Least significant difference	6.4	0.43	2.4	5

### ***Development of wheat quality baseline data***

Baseline wheat quality data can be used to match wheat flour with specialty markets, assess how genetics and climate interact to impact wheat composition and quality, and provide a baseline for evaluating year-to-year fluctuations (Caffe-Treml et al. 2010a, 2010b). Tables 30.5 and 30.6 present the baseline details.

For the Spring Wheat baseline data, 218 samples were obtained from five diverse South Dakota growing locations over three growing seasons. The samples were subjected to full milling and baking analysis by the USDA Hard Red Spring Wheat Quality Laboratory in Fargo, North Dakota.

For the Winter Wheat baseline data, 96 samples were obtained from research plot seed samples collected across eight locations for the Crop Performance Trial (CPT) and three locations for the Advanced Yield Trial (AYT). Samples were subjected to full milling and baking analyses by the USDA-ARS Winter Wheat Quality Laboratory in Manhattan, Kansas.

### ***Summary***

Wheat genetics and growing conditions eventually translate into products with specific quality traits. The challenge for both the researcher and producer is to maximize the value-added food traits that are most desirable for the consumer. An understanding of the constituent/functionality relationship or structure/functionality relationship within the wheat is essential for devising practical solutions relating to sub-optimal baking performance, decreased milling yield or reduced nutritional content.

Newer information on dough-mixing behavior and the energy required to produce optimal bread dough will provide a more complete picture to this understanding. Well-designed studies will also delineate environmental factors or growing practices that may impart valuable traits in existing and new wheat varieties.

**Table 30.5. Hard red wheat quality baseline data.** Data from SDSU Spring Wheat and Winter Wheat Breeding Programs.

WHEAT DATA							
		Wheat Color	Test weight (lbs/bu)	1000 Kernel weight (g)	Protein (14 % mb)		
2007	RELEASED VARIETIES	RED	58.1	28.3	14		
		WHITE	56.2	25.5	14.3		
	BREEDING LINES	RED	58.6	28.5	13.8		
		WHITE	58.9	27.6	13.5		
2008	RELEASED VARIETIES	RED	60.2	33.8	12.8		
		WHITE	60	29.3	13.1		
	BREEDING LINES	RED	58.9	29.5	13.2		
		WHITE	60.1	29.5	13		
FLOUR DATA (14% mb)							
		Wheat Color	Flour Extraction (%)	Flour protein (%)	Flour ash (%)		
2007	RELEASED VARIETIES	RED	70.6	12.9	0.48		
		WHITE	69.4	13.1	0.48		
	BREEDING LINES	RED	58.6	12.8	0.51		
		WHITE	58.9	13.1	0.50		
2008	RELEASED VARIETIES	RED	60.2	12.9	0.39		
		WHITE	60	11.7	0.38		
	BREEDING LINES	RED	58.9	12	0.40		
		WHITE	60.1	11.8	0.38		
DOUGH RHEOLOGY (Mixograph data)							
		Wheat Color	Water Absorption (%)	Mixing time (min)	Mixing tolerance (min)		
2007	RELEASED VARIETIES	RED	64.3	4.00	3.75		
		WHITE	63.8	3.38	2.33		
	BREEDING LINES	RED	64.0	3.89	3.89		
		WHITE	62.6	3.15	3.15		
2008	RELEASED VARIETIES	RED	62.7	4.27	3.50		
		WHITE	61.3	4.18	2.67		
	BREEDING LINES	RED	62.3	4.60	3.81		
		WHITE	61.0	3.72	2.67		
BAKING DATA							
		Wheat Color	Water Absorption (%)	Mixing Time (min)	Loaf weight (g)	Crumb Score	Loaf Volume (cc)
2007	RELEASED VARIETIES	RED	63.3	5.50	149.8	3.55	951.9
		WHITE	62.7	4.21	149.2	3.50	971.7
	BREEDING LINES	RED	62.9	5.08	149.7	3.86	1005.0
		WHITE	60.4	3.85	148.0	3.16	918.3
2008	RELEASED VARIETIES	RED	62.7	5.04	150.7	3.85	890.0
		WHITE	59.7	4.47	148.3	4.07	885.0
	BREEDING	RED	61.2	5.77	148.9	3.90	933.1

**Table 30.6. Hard spring wheat baseline data that was collected between 2006 and 2009.** Data from SDSU Spring Wheat and Winter Wheat Breeding Programs.

WHEAT DATA					
		Test weight (lbs/bu)	1000 Kernel weight (g)	Protein (%)	Ash (%)
2007	RELEASED VARIETIES	59.8	30.4	15.1	1.52
	BREEDING LINES	60.1	30.4	14.8	1.46
2007	RELEASED VARIETIES	60.0	30.0	14.2	1.65
	BREEDING LINES	60.5	30.5	14.0	1.63
2008	RELEASED VARIETIES	59.3	32.0	13.9	1.54
	BREEDING LINES	59.4	31.4	13.5	1.49
2009	RELEASED VARIETIES	59.2	33.0	14.5	1.60
	BREEDING LINES	59.1	32.7	14.1	1.61
FLOUR DATA					
		Flour Extraction (%)	Flour protein (%)	Flour ash (%)	
2006	RELEASED VARIETIES	60.8	13.7	0.36	
	BREEDING LINES	60.0	13.2	0.35	
2007	RELEASED VARIETIES	60.3	13.2	0.38	
	BREEDING LINES	59.0	12.9	0.38	
2008	RELEASED VARIETIES	59.0	12.7	0.38	
	BREEDING LINES	59.8	12.1	0.37	
2009	RELEASED VARIETIES	61.3	13.4	0.45	
	BREEDING LINES	60.1	13.0	0.41	
DOUGH RHEOLOGY (Mixograph data)					
		Water Absorption (%)	Mixing time (min)	Mixograph score (min)	
2006	RELEASED VARIETIES	60.77	4.90	4	
	BREEDING LINES	60.8	5.84	5	
2007	RELEASED VARIETIES	61.3	5.59	5	
	BREEDING LINES	61.0	5.86	6	
2008	RELEASED VARIETIES		5.76	6	
	BREEDING LINES		9.03	6	
2009	RELEASED VARIETIES		4.36	6	
	BREEDING LINES		5.70	6	
BAKING DATA					
		Water Absorption (%)	Mixing Time (min)	Loaf Volume (cc)	
2006	RELEASED VARIETIES	57.5	2.05	181.2	
	BREEDING LINES	56.7	1.99	182.2	
2007	RELEASED VARIETIES	60.2	2.44	176.1	
	BREEDING LINES	60.6	2.52	174.7	
2008	RELEASED VARIETIES	57.2	2.62	183.1	
	BREEDING LINES	55.8	3.36	181.1	
2009	RELEASED VARIETIES	58.9	2.1	196.4	
	BREEDING LINES	58.4	2.59	199.9	

#### Additional information and references

Blumenthal, C.S., I.L. Batey, C.W. Wrigley, and E.W.R. Barlow. 1991. Seasonal changes in wheat grain quality associated with high temperature during grain filling. *Aust. J. Agric. Res.* 42:21-30.

Caffe-Tremblé, M., K.D. Glover, P.G. Krishnan, and G.A. Hareland. 2010. Variability and relationships among Mixolab, Mixograph, and baking parameters based on multi-environment spring wheat trials. *Cereal Chemistry*. 87(6):574-580.

Caffe-Tremblé, M., K.D. Glover, P.G. Krishnan, K.D. Bondalapati, J. Stein, and G.A. Hareland. 2010b. Effect of wheat genotype and environment on relationships between dough extensibility and breadmaking quality. *Cereal Chemistry*. 88(2):201-208.

Fuertes-Mendizábal, T., A. Dizpurua, M.B. González-Maró, and J.M. Estvillo. 2010. Improving wheat breadmaking quality by splitting the N fertilizer rate. *European J. Agronomy*. 33:52-61.

Hamada, A.S., C.E. McDonald, and L.D. Sibbitt. 1982. Relationship of protein fractions of spring wheat flour to baking quality. *Cereal Chemistry*. 59:296-301.

Kharel, T., D.E. Clay, D. Beck, C. Reese, and C.G. Carlson. 2011. Nitrogen and water effects on winter wheat yield, N and water use efficiency, and dough quality. *Agron. J.* (In progress).

Reese, C. 2009. Nitrogen and water impacts on hard red spring wheat yield, quality, canopy reflectance and income in South Dakota. South Dakota State University Ph.D. Thesis.

Regnier, S., R. Holcomb, and P. Royas-Duarte. 2009. Relating wheat quality to end-product quality. FAPC-129. Oklahoma State University Agricultural Products Center. Available at <http://www.fapc.okstate.edu/files/factsheets/fapc129.pdf>

Shewry, P.R., and A.S. Tatham. 1997. Disulfide bonds in wheat gluten proteins. *J. Cereal Science* 25:207-227.  
Wieser, H., and W. Seilmeier. 1998. The influence of nitrogen fertilization on quantities and proportions of different protein types in wheat flour. *J. Sci. Food Agric.* 76:49-55.

#### Acknowledgments

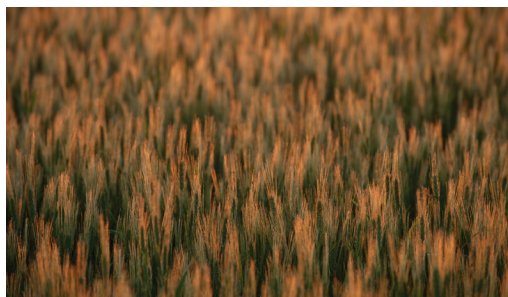
The authors wish to thank the South Dakota Wheat Commission and the South Dakota Agricultural Experiment Station for their support of scientific research in the area of wheat production and wheat end-use evaluations.

---

Krishnan, P.G., J. Darby, W. Berzonsky, and K.D. Glover. 2012. Quality traits and end-use functionality of South Dakota hard red spring and hard red winter wheat. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrowWheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.







## CHAPTER THIRTY-ONE

# Using Molecular Biology for Management and Genetic Enhancements

*Paul Rushton* ([Paul.Rushton@sdstate.edu](mailto:Paul.Rushton@sdstate.edu))

*Wanlong Li* ([Wanlong.Li@sdstate.edu](mailto:Wanlong.Li@sdstate.edu))

*Stephanie Hansen* ([Stephanie.Hansen@sdstate.edu](mailto:Stephanie.Hansen@sdstate.edu))

The purpose of this chapter is to describe how molecular biology, molecular enhancements, and integrated crop production research can lead to genetic improvements and the development of management systems that fully utilize the genetic capacity of wheat varieties.

### Rules of Thumb for Using Molecular Biology to Increase Profitability

- Molecular biology provides information that speeds up crop breeding by approximately 50%.
- Unlike corn, soybean, and rice, the sequencing of the wheat genome continues. When the wheat genome is sequenced (estimated 5 years), the ability to enhance both genetics and management practices should be improved.
- Molecular biology provides information that can be used to better understand how genes, climate, and management interact.

### Introduction

Researchers are often asked how our experiments with genes and DNA in the laboratory can possibly benefit farmers and their crops out in the field. Sometimes, research scientists seem just too far removed from the reality of what happens on the land. Can these molecular approaches really lead to benefits for growers and producers? The short answer to that is yes. Information produced by molecular biology can be used to:

- Improve our understanding on how wheat grows and develops.
- Develop information that can lead to improved Best Management Programs.
- Speed up and increase the efficiency of wheat breeding programs.

Our ancestors started manipulating genes in wheat around 12,000 years ago. These early farmers had the same goals as we do, and in many ways used similar approaches to improve their crops. The wild relatives of our crop plants had many undesirable qualities that made early farming much harder than it is today. In 1884, Alfonse De Candolle wrote in *Origin of Cultivated Plants* that:

a cultivated species varies chiefly in those parts for which it is cultivated. . . . We may expect, therefore, to find the fruit of a wild fruit tree small and of a doubtfully agreeable flavour, the grain of a cereal in its wild state small, the tubercles of a wild potato small, the leaves of indigenous tobacco narrow . . . (13-14)

The transformation from wild to domesticated varieties is called the *Domestication Syndrome*. In this process, spontaneous mutations occur in wild populations and these mutant individuals are selected for use by humans for their more desirable traits. Interestingly, the traits selected for “under” domestication would often be detrimental to the crop in the wild. As a consequence, fully domesticated crops may not survive in the wild without human intervention.

Wheat provides an excellent example of this. The ears of wheat are separated from the stem that bears them by a structure called the *rachis*. Wild forms of wheat need to disperse seeds effectively, so they have easily shattered ears with brittle rachises. When the wheat seeds mature, the rachis shatters and the seeds penetrate surface litter embedding into ground cracks. This is an important mechanism for effective seed dispersal. The problem with this is that when the seeds fall they also become difficult for humans to gather. Wild forms of wheat, such as Wild Emmer, have a brittle rachis, therefore making harvesting time consuming and inefficient.

During early wheat domestication, farmers selected for a rare single gene mutation (*br* – brittle rachis) that prevents shattering (Dubcovsky and Dvorak 2007). This mutation is lethal in the wild (because the seeds fail to drop), but conveniently concentrates the seeds for human gatherers. All domesticated forms of wheat have this mutation.

Wild wheat also had tough glumes, making threshing difficult. A genetic mutation converting hulled wheat into free-threshing wheat was selected for, and is present in Durum and Bread Wheat, but not Emmer.

The main gene that is responsible for this free-threshing habit is called *Tg* (tenacious glume). Another gene that also produces free-threshing wheat is simply called *Q*. *Q* is a transcription factor. Transcription factors are proteins that turn other genes on or off. Molecular biology has shown that most of the key domestication genes in wheat and other cereal species are transcription factors (Table 31.1). Understanding transcription factor genes is important because mutation in a single factor can turn a whole process on or off.

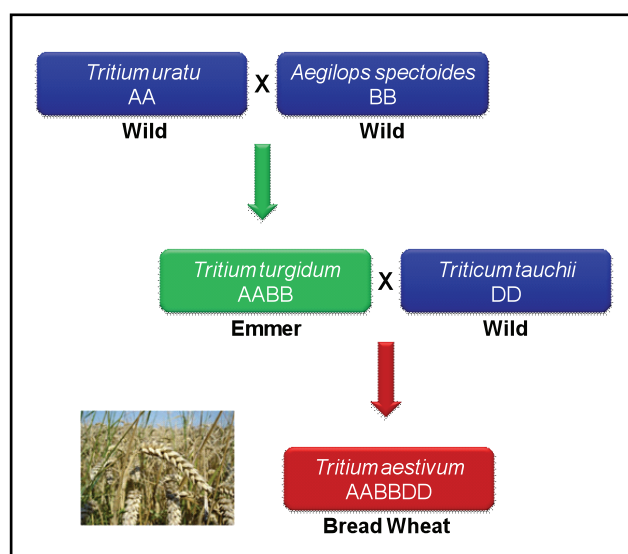
**Table 31.1. Selected genes and their roles in cereals.**

Gene	Crop species	Type of gene	Role
<i>Q</i>	Wheat	AP2 Transcription factor	Free-threshing
<i>Rht-B1</i>	Wheat	GRAS Transcription factor	Semi-dwarf plant
<i>Tb1</i>	Maize	TCP Transcription factor	Lateral branches
<i>TGA</i>	Maize	SBP Transcription factor	Glume size
<i>SH4</i>	Rice	MYB Transcription factor	Grain shattering
<i>qSH1</i>	Rice	BELL HD Transcription factor	Grain shattering

### *The family history of wheat*

Molecular biology can speed up breeding programs. To understand how these new molecular methods can do this, first we need to consider wheat itself. First, wheat is different in several important respects from corn, rice and barley. Bread wheat is the result of multiple crosses between goat grass (the “grandmother” of wheat—**gene set AA**) and wild wheat (the “grandfather” of wheat—**gene set BB**). The progeny of these crosses enabled a second type of cross between durum (called the “mother” of wheat—**gene set AABB**) and another goat grass (called the “father” of wheat—**gene set DD**) (Fig. 31.1).

The result is that Bread Wheat has three genomes: the A, B, and D genomes. This cross (**gene set AABBDD**) was probably made by ancient farmers living in what we now call Iraq. The resultant cross demonstrated “hybrid vigor,” and outperformed its wild ancestors in yield and environmental adaptation, leading to further cultivation and hybrid improvement. The initial crosses, which were a boon to ancient farmers, also had the unfortunate side effect of creating an extremely complex genetic code for twenty-first century scientists.



**Figure 31.1. A diagram showing the genetic source of bread wheat.**  
(Source: Paul Rushton)

The complete set of genes (a gene is a section of DNA that is responsible for traits) that makes up any living organism is called its **genome**. This can be compared to a large book of blueprints, for instance, or the code that makes up a computer program. Wheat has a huge genome that is forty times larger than that of rice, and fifteen times the size of soybean. Because of its genetic background we described previously, wheat potentially has three genes for each trait. This complicates matters considerably. For example, if we want to produce an improved wheat variety by eliminating a gene with negative properties, we are faced with the possibility that we will have to actually eliminate three genes because each of the three genomes has a copy of this gene. Eliminating only one gene is likely to have no effect because there will still be two of these genes left that can carry out the job that this gene performs.

### ***The sequence of the wheat genome***

To effectively use molecular biology for genetic improvement, we need the genetic code. Given that wheat contains three genomes, making sense of the genetic code is like trying to assemble three jigsaw puzzles that have been mixed in the same box. It was therefore a surprise to wheat scientists when it was recently announced that the wheat genome had been sequenced. This accomplishment, although immensely important, was not quite what it seemed. Unfortunately, what the group of scientists had produced was not a genome sequence in a form that scientists and breeders can easily use.

A simple jigsaw puzzle example again explains what happened. The scientists had chopped the wheat genome up into small chunks and sequenced all of the chunks—just like making all of the pieces of a jigsaw puzzle, without putting the puzzle together. Without putting the pieces of the jigsaw puzzle together, you cannot see the complete picture. Exactly the same is true of the sequence that was generated from wheat in the UK. The small pieces of DNA sequence now need to be put together (assembled) before we can use them.

The International Wheat Genome Sequence Consortium, a more than 200-member organization of growers, breeders and scientists not affiliated with the U.K. project, issued a press release in Washington, D.C. on August 30, 2010 <http://www.wheatgenome.org/News-and-Reports/News/Significant-Work-Still-Needed-to-Really-Crack-Wheat-s-Genetic-Code>. They echoed what the UK funding body had said, namely that “significant work remains to be done to achieve a complete genome sequence” <http://www.bbsrc.ac.uk/news/archive/2010/2010-archive-index.aspx>.

In contrast, the International Wheat Genome Sequence Consortium is attempting to produce the complete assembled wheat genome “in the next five years.” This seems a reasonable target. Some believe that the develop of the wheat genome will be “the most significant breakthrough in wheat production in 10,000 years.” Current wheat growers live in exciting times.

### ***Why will the wheat genome sequence be such a big breakthrough?***

Our forefathers improved wheat in an untargeted way. They observed mutants and if this resulted in an improvement, they selected from those plants. It was completely dependent on the occurrence of natural mutations, which is a slow process. By contrast, modern molecular approaches are rapid and highly targeted.

We take a specific gene or genes and alter it. We then monitor the effect to see if there is an improvement in the wheat cultivar in some important trait such as yield or resistance to disease. To do this effectively, however, we need all of the genes in wheat so that we know what to manipulate. We can’t modify something if we don’t know of its existence. The genome sequence provides the blue print for this approach.

When a plant is affected by drought or water stress, are there management practices producers can implement to help reduce the yield loss? Probably. Research on corn indicates that corn plants under water-deficit stress in summit landscape positions are more susceptible to disease and nutrient stress than non-water-deficit corn in footslope positions (unpublished data, Clay et al.). This can be compared to a human’s immune system; if you stress a person by withholding water, nutrients, or sleep, the person’s immune system will be lowered. It seems to be the same with plants.

Because not all fields have consistent nutrient or water availability, applying a field-wide fungicide can be wasteful, as some areas just don't need it. Molecular biology can lead to in-field tests that will allow producers to assess the activity of specific genes. This information can be used to improve management decisions. At the present time, producers and consultants can make assumptions regarding what management options are needed, but until we understand what is really happening inside the plant, they are just "best-guesses."

### ***What are "molecular approaches?"***

Molecular techniques can be integrated into traditional breeding and agronomic production approaches. When linked with breeding, molecular biology techniques speed up the cultivar selection process. Molecular approaches can also provide critical field production information needed to take full advantage of the genetic potential of crops. For example, by using molecular biology, the impacts of seeding density, fertilizer rates, and heat stress on the up-and-down regulation of specific genes can be assessed. The bottom line is that molecular biology enhances traditional testing approaches. Molecular tools that are routinely used in breeding and crop production research are molecular markers and micro-arrays. The development of transgenic corn and soybeans relied on molecular approaches.

### ***Molecular markers***

A breeder crosses one wheat variety with another, getting 500 seeds that potentially contain the trait being bred for. Before Marker Assisted Selection (MAS), the breeder would have to grow out all 500 seeds and assay them for the desired trait, sometimes to full maturity, depending upon which trait was being sought. This method uses valuable greenhouse or field space, labor, and resources. Using MAS, breeders can germinate the seeds, take a small tissue sample, and save the seedlings that have the marker for the desired trait.

Perhaps only ten of the 500 seeds contain the trait, but breeders will now only have to grow out those ten plants knowing they contain the desired trait. Markers are unique, short strings of DNA located near a gene of interest. Small genetic differences in the DNA sequence of traits can be responsible for one plant being resistant to a disease and another not being resistant. Using MAS, the time required to bring a new trait to the public is reduced by 50%. In wheat, approximately 6,000 molecular markers have been discovered. These markers function as an additional set of "index tabs" in the wheat set of blueprints.

### ***Microarray technology assesses plant responses to stress***

Plants respond to soil, climate, and pest stress by changing the genes that are expressed. Microarray (or chip) technology allows us to pinpoint which genes have been affected by stress treatments by comparing the gene expression of a control plant to the gene expression of a test (or treated) plant. Wheat chips have been used to explore gene expression during pathogen infection, environmental stress, and plant development. In corn we have used microarray analysis to assess the influence of plant density and weed competition on gene expression. Understanding what is happening in the plant under stressful conditions will lead to better decision making regarding planting populations, choice of variety, fungicide and fertilizer applications, and other management decisions.

### *Some routes to improved wheat varieties*

Traits that wheat breeders are specifically interested in include: vernalization and photoperiod response, plant architecture, grain quality, pest resistance, and tolerance to abiotic stresses. **Vernalization** and **photoperiod responses** are of interest because they influence the wheat flowering time. Increasing the length of time of grain filling may lead to higher yields.

**Plant architecture** is important because it impacts the ability of the plant to withstand lodging. As stand density and use of fertilizer increased, lodging became a critical problem. Approaches to solve this problem are breeding shorter plants and delaying N fertilizer applications (Chapter 11). One of most significant contribution of the “green revolution” is the reduction of wheat plant height. Two *reduced height (Rht)* (Table 31.1) genes are now found in most modern semi-dwarf wheat cultivars. The manipulation of these genes significantly reduced wheat plant heights to 80 to 90 cm and improved wheat resistance to lodging.



**Figure 31.2. Lodging in wheat has been greatly improved by selective breeding centered on the two *Rht* genes.** (Photo courtesy of <http://faculty.uca.edu/johnh/greenrev3390.htm>)

Research has been conducted to understand how genetics, management, and climate interact to impact **grain quality** (protein composition, baking, and mixing characteristics). Progress has been made in understanding the genetic components of wheat grain quality in two aspects: grain hardness and grain protein content. Genes controlling hardness of wheat have been discovered (PinA and PinB genes) (Hogg et al. 2004). Varieties with specific mutations (sequences) in these genes are hard textured, while other varieties have sequences contributing to the soft wheat type.

Genes controlling the protein content of wheat have a direct effect on the bread-making quality of the grain produced. Several of these genes that effect protein content have been discovered in wheat and have been manipulated in modern-day wheat, with more improvements to come. <http://deltafarmpress.com/promise-better-wheat-varieties>

**Disease resistance** research has focused on rotational effects as well as better understanding seedling and adult plant resistance. Seedling resistance is race-specific, whereas adult plant resistance is broad-spectrum. Adult plant resistance is more durable, although at lower levels compared to seedling resistance. More recently, progress has also made in understanding wheat plant susceptibility to rusts, powdery mildew, tan spot, and plant resistance to Hessian fly and greenbugs. Improving disease resistance is one of the areas where molecular biology holds most promise for breeders and growers.

Wheat production is facing numerous challenges from drought, excess water, heat, salinity, and other soil-derived **toxicities**. Complex traits such as drought and heat-stress tolerance have started to reveal themselves through the use of molecular tools. It will take hard work and





**Figure 31.3. Fusarium head blight and rust are two diseases that researchers are battling through molecular means.** (Photo courtesy of Mary Burrows, Montana State University, Bugwood.org)

time to understand traits such as these so that we may use them to our advantage. By better understanding how the plant responds to stress, we can develop more effective management practices.

In the future by linking our breeding, crop production, and molecular biology programs, we will be more effective at producing resilient tools that can respond to climate variability. Compared to rice, maize and soybean, a bottleneck limiting wheat research is the lack of a complete set of “blueprints.”

Currently, labs in 16 countries within the International Wheat Genome Sequencing Consortium (IWGSC) are engaged in decoding this immense book of blueprints. This knowledge will increase our capacity, efficiency, and dimensions in dealing with complex traits, such as drought and heat tolerance. Successful decoding of these blueprints will unlock the bank and pave the way to realize the potential of the sleeping wheat germplasm. As mentioned above, wheat growers in the twenty-first century live in exciting times.

#### Additional information and references

Bennett, David. *The Promise of Better Wheat Varieties*. Delta Farm Press, December 28, 2006. Available at <http://deltafarmpress.com/promise-better-wheat-varieties>

Biotechnology and Biological Sciences Research Council. *UK researchers release draft sequence coverage of wheat genome*, news release, August 27, 2010. Available at <http://www.bbsrc.ac.uk/news/archive/2010/2010-archive-index.aspx>

de Candolle, Alphonse. 1884. *Origin of Cultivated Plants*. Edited by Paul C. Kegan, Trench & Co., London.

Dubcovsky, J., and J. Dvorak. 2007. *Genome plasticity: a key factor in the success of polyploid wheat under domestication*. *Science* 316:1862-1866.

Hogg, A.C., T. Sripo, B. Beecher, J.M. Martin, and M.J. Giroux. 2004. *Wheat puroindolines interact to form friabilin and control wheat grain hardness*. *Theor Appl Genet* 108(6):1089-97.

International Wheat Genome Sequencing Consortium (IWGSC). Available at <http://www.wheatgenome.org>

International Wheat Genome Sequencing Consortium. *Significant work still needed to really crack wheat's genetic code*, news release, September 9, 2010. Available at [www.wheatgenome.org/News-and-Reports/News/Significant-Work-Still-Needed-to-Really-Crack-Wheat-s-Genetic-Code](http://www.wheatgenome.org/News-and-Reports/News/Significant-Work-Still-Needed-to-Really-Crack-Wheat-s-Genetic-Code)

#### Acknowledgements

Support was provided by SDSU, South Dakota 2010 Initiative through the SD Drought Tolerance Center, USDA-AFRI, and the SD Agricultural Experiment Station.

---

Rushton, P.W. Li, and S. Hansen. 2012. Using molecular biology for management and genetic enhancements. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.





## CHAPTER THIRTY-TWO

# On-Farm Research Protocols

C. Gregg Carlson ([Gregg.Carlson@sdstate.edu](mailto:Gregg.Carlson@sdstate.edu))

The widespread use of yield monitors and global position systems (GPS) provides the opportunity for on-farm research. On-farm studies can investigate questions ranging from fungicides to seeding rates. Similar protocols can be used for a wide variety of questions. This chapter provides research protocols for: 1) site-specific seed population, and 2) site-specific optimum phosphorous application.

### ***Protocol for site-specific seeding rates***

The purpose of this section is to provide research protocols for site-specific seeding rates. This protocol is designed to help address the increasing cost of seed, the variable response of different seed populations across the landscape, and the significant change in genetic yield potential of newly developed wheat varieties.

A grower with a variable rate planter and yield monitor GPS-equipped combine will plant ½-mile strips (field length of width greater than the combine header) at 600,000, 900,000, 1,200,000, and 1,500,000 seeds/acre (13.8, 20.7, 27.5, and 34.4 seeds/ft<sup>2</sup>). The width of the strips must be wide enough to insure that at least one “pure” combine pass is contained within each strip. “Loads” should be used in the yield monitor to identify each pure planting rate combine pass. Strips should be planted as shown in Figure 32.1.

### ***Grower requirements***

1. Apply at least three complete sets of alternating strips of the four rates across the length of the field. Document cultural practices such as planting date, variety, condition of seed bed, etc. If three producers are interested in collaborating, each producer can apply one set of strips.
2. Except for the planting population, uniform applications of inputs should be maintained.

3. Accurately record the (A-B) beginning and ending latitude and longitude points of each strip. If rows are not straight (not planted on an A-B line with an autosteer), an agronomy professional should walk the strip centers with a recording GPS receiver.
4. The trial must be harvested with a data recording, GPS-equipped combine. The yield monitor must have been recently calibrated for the variety of wheat in the trial. Harvest the entire trial area on the same day. Each pass should be recorded as a unique load. Combine direction of travel should be the same for all strips within a set. To accomplish analysis, the GPS yield monitor data should be submitted to the SDSU Drought Center as raw yield data from the memory card.
5. Allow the SDSU Drought Center to use submitted and collected data for research, educational, and informational purposes.
6. If it is possible, provide the SDSU Drought Center with production records as well as yield monitor data for the previous five years.
7. Document as much auxiliary information as is possible (precipitation, weed, insect, disease problems, soil test analysis, etc.).

#### ***SDSU Drought Center responsibilities***

1. Return a report analyzing the treatment differences to include an optimized planting algorithm.
2. Keep data in a confidential manner that can't be linked back to the individual producer by other parties. Only resultant recommendations composited with all data sets will be made public.
3. Take stand counts in each strip.



**Figure 32.1. Field protocols for the four field population rates.**

#### ***Protocol for determining optimum site-specific phosphorous rates***

The purpose of this section is to quantify the agronomic and economic impacts of on-the-go changes to phosphorous fertilization. This information is needed to increase profitability. After the initial fertilizer application, the field will be yield monitored for five years with the goal of determining the optimum long-term soil test level.

### ***Brief summary***

A field with a low phosphorous soil test level (Olson P of ~5ppm) will be selected. Previous five years of yield monitor data will be used to select (SDSU Drought Center) strip locations. Strips will be laid out on a ½-mile length of field in a width that is equal to the local fertilizer supplier's applicator. Strips will be fertilized perpendicular to the field variability.

Treatments will be:

1. 500 lb of actual  $P_2O_5$ /Acre (*if DAP is applied, 18-46-0, this will be 1087 lb DAP/acre—after application soil test ~30*).
2. 300 lb of actual  $P_2O_5$ /Acre (*652 lb DAP/acre—after application soil test ~20*).
3. 100 lb of actual  $P_2O_5$ /Acre (*217 lb DAP—after application soil test ~10*).
4. 0 lb (control) of actual  $P_2O_5$ /Acre.

Harvesting with a GPS yield monitor, data logging-equipped combine must ensure at least one “pure” combine pass (not mixing yields from two strips) within each strip. Loads should be used in the yield monitor to identify each pure rate pass.

### ***Grower requirements***

Apply three sets of the four P rates across the length of the field. If three producers are interested in collaborating, each producer can apply one set of strips. Each year, document the cultural practices such as planting date, hybrid, condition of seed bed, etc. This experiment is designed to last five years.

*The major requirements are listed as follows:*

1. Apply at least three complete sets of alternating strips of the four rates across the length of the field. Document cultural practices such as planting date, variety, condition of seed bed, etc. If three producers are interested in collaborating, each producer can apply one set of strips.
2. Except for the planting population, uniform applications of inputs should be maintained.
3. Accurately record the (A-B) beginning and ending latitude and longitude points of each strip. If rows are not straight (not planted on an A-B line with an autosteer), an agronomy professional should walk the strip centers with a recording GPS receiver.
4. The trial must be harvested with a data recording, GPS-equipped combine. The yield monitor must have been recently calibrated for the variety of wheat in the trial. Harvest the entire trial area on the same day. Each pass should be recorded as a unique load. Combine direction of travel should be the same for all strips within a set. To accomplish analysis, the GPS yield monitor data should be submitted to the SDSU Drought Center as raw yield data from the memory card.
5. Allow the SDSU Drought Center to use submitted and collected data for research, educational, and informational purposes.
6. If it is possible, provide the SDSU Drought Center with production records as well as yield monitor data for the previous five years.
7. Document as much auxiliary information as is possible (precipitation, weed, insect, disease problems, soil test analysis, etc.).
8. Accurately record the (A-B) beginning and ending end points of each strip. If rows are not straight (not applied on an A-B line with an auto steer), an agronomy professional will walk the strip centers with a recording GPS receiver.

9. 0-6 inch soil sample taken and analyzed for each strip approximately every 400 ft in each ½-mile strip (starting 200 ft from field beginning) before treatment and in years 2, 3, 4, and 5. (If 400-ft sample is on side slope and the next 400-ft sample is on the other side of the slope, sample point can be move to the top or bottom of the hill. Mark points with GPS).
10. Fifteen cores (cores to be composited) need to be pulled within 20 ft of each 400-ft flag.
11. Strips must be the width of spreader booms (commonly 70 ft).
12. Fields should be of low phosphorous fertility (Olson or Bray ~5 or less) and without a manure application history.
13. In the following years, the producer's normal flat rate of fertilizer should be applied and documented (normal rate of what producer uses). Soil tests for phosphorus must be pulled every year on strips.
14. Use the same lab every year to do analysis.
15. Record and archive yield data all five years of study.
16. Seeding rate should remain constant across the entire variable rate P study.

#### ***SDSU Drought Center responsibilities***

1. Return a report analyzing the treatment differences.
2. Keep data in a confidential manner that can't be linked back to the individual producer by other parties. Only resultant state-wide or area-wide recommendations will be made public.



**Figure 32.2. Field treatment for the four P rates.**



**Additional information and references**

<http://www.agry.purdue.edu/ext/ofr/protocols.html>

<http://www.agry.purdue.edu/ext/ofr/protocols/PurdueCornFungicideProtocol.pdf>

[http://york.unl.edu/c/document\\_library/get\\_file?uuid=11797937-554d-4142-b8d8-9c59e7d9fb0a&groupId=135081&pdf](http://york.unl.edu/c/document_library/get_file?uuid=11797937-554d-4142-b8d8-9c59e7d9fb0a&groupId=135081&pdf)

**Acknowledgements**

*Support provided by South Dakota State University, South Dakota Drought Tolerance Center, and the South Dakota Wheat Commission.*

---

Carlson, C.G. 2012. On-farm research protocols. *In* Clay, D.E., C.G. Carlson, and K. Dalsted (eds). iGrow Wheat: Best Management Practices for Wheat Production. South Dakota State University, SDSU Extension, Brookings, SD.





## CHAPTER THIRTY-THREE

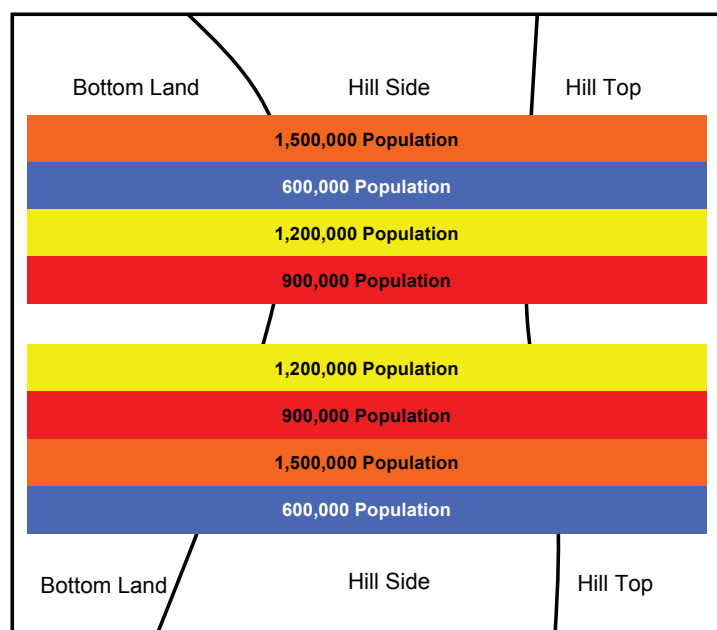
# On-Farm Research and Analysis

*C.G. Carlson* ([Gregg.Carlson@sdsta.edu](mailto:Gregg.Carlson@sdsta.edu))

*Cuirong Ren* ([Cuirong.Ren@sdsta.edu](mailto:Cuirong.Ren@sdsta.edu))

*D.E. Clay* ([David.Clay@sdsta.edu](mailto:David.Clay@sdsta.edu))

This chapter provides a primer on analyzing findings from on-farm research studies. This chapter complements Chapter 32. In many on-farm studies, treatments are implemented across landscapes (Fig. 33.1). To make informed, science-based decisions, understanding data collection and simple arithmetic calculations used for statistical analysis and data interpretation are critical. Microsoft Excel is used in the following discussion.



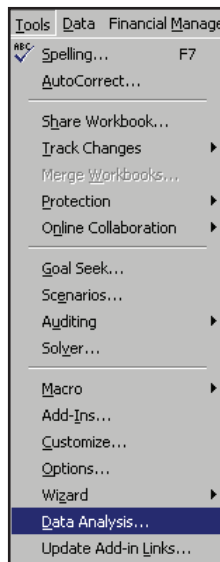
**Figure 33.1. On-farm research study, where treatments are placed perpendicular to elevation.** (Carlson et al. 2011)

### ***Loading the software into Microsoft Excel***

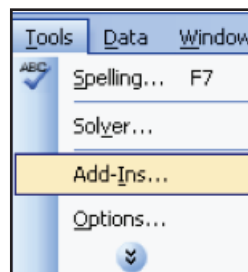
For this section, you will need to load software into your Microsoft Excel. To load these programs, follow the discussion below. Different protocols are needed for loading the required software in Microsoft Excel 1997-2003 and 2007.

In Microsoft Excel 97-03:

1. Use Excel's Tools menu, Data Analysis (Fig. 33.2).

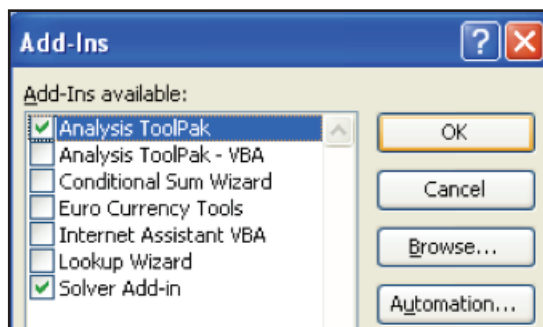


**Figure 33.2. Step 1 in loading required software in Excel 97-2003.**



**Figure 33.3. Step 2 in loading required software.**

2. If the above Data Analysis menu is not available, you will need to turn it on (Fig. 33.3). To do this, select Tools and highlight Add-Ins as below.
3. From the Add-Ins menu, select with a check Analysis ToolPak as shown in Figure 33.4. Now the Data Analysis line will show up from the Tools menu.



**Figure 33.4. Step 3 in loading required software.**

4. From the Data Analysis menu, Anova: Two-Factor Without Replication is selected and OK is pushed.

In Microsoft 2007, use the following protocols:

1. Select the Office (File) Button, left hand corner.
2. Select Excel options.
3. Select Add-Ins.
4. Select analysis ToolPak.
5. Select Go.
6. Click Analysis ToolPak.
7. Click OK.

### ***Introduction***

On-farm studies can be used to test product claims. For example, at a local farm show, Mel met a dynamic salesman, Lioekans, who was selling a new superior yield enhancing product (this miracle product is sold under the trade name “Super Soak”).

Lioekans sells this incredible product for \$80.00/gallon. Since Mel showed some interest, Lioekans makes a farm visit to Mel’s place. Lioekans suggested that Mel try a free gallon of Super Soak on a single ten-acre strip (suggested application rate is 12.8 ounce/acre) in his field. If Mel gets a yield advantage as advertised, he will agree to use Super Soak on his entire farm next year. If there is no advantage to Super Soak, then the \$80.00 valued product that Lioekans gave Mel is absolutely free without obligation.

Before we go on, let us ask an important question. If Super Soak has zero impact on yield, what is the probability of one untreated strip “A” out yielding a second untreated strip “B”? The answer is 50%. Now, what is the random chance that Super Soak out-yielded the non-treated area if two sets of treated and non-treated strips are used? The answer is 25% ( $0.5 \cdot 0.5$ ). How about if the material is applied to three sets of strips? The answer is 12.5% ( $0.5 \cdot 0.5 \cdot 0.5$ ).

After listening to Lioekans’s sales pitch, Mel agreed to try the product, but with the stipulation that Mel would test the product using four randomly placed replicated strips. Additionally, before Mel agreed to buy the product, the treated plots had to show a statistically significant higher yield at the 95% probability level. With these criteria in place, Lioekans agreed to the terms, drove out of the yard, and was never seen again.

To improve agricultural management, new techniques are frequently created and compared with traditional techniques. On-farm experiments are one approach for comparing the practices on your farm.

### ***On-farm research***

Through on-farm research, the influence of a treatment(s) on a measurable variable is investigated. In these experiments, the independent variables are manipulated, whereas, dependent variables are measured. For example, in an N rate experiment where different N rates are applied, the independent variable is N rate and dependent variable is yield.

In an erosion study where the influence of cultivation on erosion is measured, the independent variable might be the number of times that a field is cultivated, while the dependent variable is the amount of erosion. Research experiments are designed to provide insights into cause and effect.

Most experiments contain replications of each treatment. Replications provide assurance that the response to a treatment is real and repeatable and not due to error, variance, or random chance. For example, if you flip a coin once and get heads, with no replication, you may predict that heads will always occur. As more replications of the flip occur, you should see that heads comes up 50% of the time and tails comes up the other 50% of the time.

To implement on-farm studies, field trials should be placed perpendicular to the landscape (Fig. 33.1). To detect differences, it is desirable to maximize the number of replicates. The minimum number of replicates is three. Additional details about this approach are available at [http://www.ipni.net/ppiweb/ppibase.nsf/\\$webindex/article=3DD9EB2C85256966006141B759745B04](http://www.ipni.net/ppiweb/ppibase.nsf/$webindex/article=3DD9EB2C85256966006141B759745B04)

### Statistics overview

Statistics are used to objectively evaluate numerical data in order to make informed decisions. Statistics involve computation and arithmetic manipulation of data that can be *qualitative* or *quantitative*. Qualitative variables have values that cannot be defined numerically (e.g., sex, plant species, or marital status), whereas, quantitative variables can be defined numerically (e.g., yield, weed density, weight).

### Means or averages

The mean, or average, of a sequence of numbers is the sum divided by the number of measurements taken. A notation for the mean or average is  $\bar{X}$ . Mathematically, this is expressed by the equation,

$$\bar{X} = \frac{\sum_{i=1}^n X_i}{n} = \frac{15}{4} = 3.75$$

This equation indicates that all values of X from the first to the last ( $n^{th}$ ) will be summed and divided by the total number of observations ( $n$ ). In Microsoft Excel, the average of numbers can be determined using the command, **=average(start list: end list)**.

### Variance and standard deviations

Unless each observation is the same number, there is variation around the average value. The variance ( $s^2$ ) provides a measure of this variation. The *variance* is a measure of precision (how close the numbers are to each other), not accuracy (how close the numbers are to the true value). The variance ( $s^2$ ) is calculated using the equation,

$$s^2 = \frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n - 1}$$

where,  $\bar{X}$  is the mean or average of the measurements,  $X_i$  are the individual measurements, and  $n$  is the number of measurements taken.

$$\bar{X} = \frac{1+5+6+3}{4} = \frac{15}{4} = 3.75$$

$$s^2 = \frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n - 1} = \frac{(1-3.75)^2 + (5-3.75)^2 + (6-3.75)^2 + (3-3.75)^2}{4 - 1} = 4.92$$



In this calculation,  $\sum$  tells you to sum the values where  $X_i$  goes from 1 to n. Using the data set where  $X_1=1$ ,  $X_2=5$ ,  $X_3=6$ , and  $X_4=3$ , the variance is calculated as follows: The standard deviation (s) is defined as the square root of the variance ( $s^2$ ). In this example the standard deviation is 2.22 ( $\sqrt{4.92}$ ). In Microsoft Excel, these terms can be calculated using the commands, =var(start of list: end of list) and =stdev(start of list: end of list).

### ***T-test***

The t-test provides a statistical comparison between means ( $\bar{X}$ ) of two normal populations with unknown, but assumed equal, variances. Further reading on this subject is suggested at [http://www.stattutorials.com/EXCEL/EXCEL\\_TTEST1.html](http://www.stattutorials.com/EXCEL/EXCEL_TTEST1.html). The ‘tails’ of the t-test refer to the extremities of the normal distribution curve, that is, one-tailed or two-tailed tests. Calculated t values are compared to t values found in a Table 33.1 to determine significance of results. Subscripts 1 and 2 refer to the two populations being comparatively tested.

$$s_{\bar{X}_1 - \bar{X}_2} = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

$$t = \frac{\bar{X}_1 - \bar{X}_2}{s_{\bar{X}_1 - \bar{X}_2}}$$

### ***Example 1. Determining the composite soil sampling requirements***

Subsamples are the number of unique counts or measurements made within a management zone. For example, 15 soil cores are composited into each sample from a management zone. Based on these 15 subsamples, a single fertilizer recommendation is determined for this zone. The accuracy of this recommendation could be improved by increasing the number of samples contained in the composite sample. The number of samples needed for a particular field (sampling requirement) is determined using the following equation.

$$n = \frac{t^2 \cdot s^2}{D^2}$$

In this example, n is the sub-sampling requirement, s is the standard deviation described above, t is the t value, and D is the desired confidence interval. The t value in the sub-sampling requirement equation comes from the t-table shown in Table 33.1.

A more complete discussion of t-tables is available at <http://www.statsoft.com/textbook/sttable.html>. Most t-tables have an “ $\alpha$ ” (pronounced “alpha”) level across the top of the table (columns) and degrees of freedom going in the vertical direction (rows). The value is  $\frac{1}{2}$  of the probability level (p). The appropriate  $\alpha$  column is determined by dividing the p value by 2. For example, if we want to have 80% confidence in the answer, i.e.,  $p = 0.2$ , then  $\alpha$  is 0.1. The number of degrees of freedom is determined by subtracting one from the number of total number of observations (n-1). A soil sample consisting of 21 cores would then have 20 degrees of freedom. So, the t value at the junction of  $p = 0.2$ ,  $\alpha = 0.10$ , and 20 degrees of freedom is 1.325. A t-table and sample calculations for demonstrating the use of the sampling requirement follow.

**Table 33.1. A simplified sample t distribution table.** The  $\alpha$  value represents the degree of significance desired in the calculations. For a two-sided test the significance level is two times the  $\alpha$  value.

Degrees of freedom	$\alpha=0.10$	$\alpha=0.05$	$\alpha=0.025$
1	3.078	6.314	12.706
2	1.886	2.92	4.303
3	1.638	2.353	3.182
4	1.533	2.132	2.776
5	1.476	2.015	2.571
6	1.44	1.943	2.447
7	1.415	1.895	2.365
8	1.397	1.86	2.306
9	1.383	1.833	2.262
10	1.372	1.812	2.228
20	1.325	1.725	2.086
$\infty$	1.282	1.645	1.96

### Example 2. Comparison of soil test results

A crop consultant would like to determine the soil test phosphorus (P) value from a field within 2 ppm of the true value 80% of the time. The manager knows that that in a previous field where he collected 21 samples, the variance ( $s^2$ ) of these samples was 25. The t value of 1.325 (Table 33.1) was calculated in the previous paragraph. Once the  $t$ ,  $s^2$ , and  $D$  values are determined, they are substituted into the subsampling requirement equation.

[http://www.ipni.net/ipniweb/insights.nsf/\\$webcontents/A7D980BC92E6385085257810005806EF/\\$file/Mikkelsen+Math+Insights\\_2010\\_pr9.pdf](http://www.ipni.net/ipniweb/insights.nsf/$webcontents/A7D980BC92E6385085257810005806EF/$file/Mikkelsen+Math+Insights_2010_pr9.pdf)

$$\alpha = (1 - 0.8) / 2 = 0.10$$

$$t_{0.10, df=20} = 1.325$$

$$n = \frac{t^2 \cdot s^2}{D^2} = \frac{1.325^2 \cdot 25}{2^2} = 10.97 \approx 11$$

This analysis indicates that 11 individual cores should be composited into a single composite sample.

### Example 3. Corn hybrid yield

Use Microsoft Excel to determine if the yields from two corn hybrids are the same or dissimilar. Yield data was randomly collected from different fields in a county.

1. Type data into Excel.
2. Select Tools.
3. Select Data Analysis.
4. Select t-Test Two-Sample Assuming Equal Variances, OK.
5. Highlight Data for Variable 1 and 2, select OK.
6. Results are shown below.

Samples	Variety 1	Variety 2
1	110	132
2	100	133
3	99	154
4	75	99
5	47	88
6	112	120
7		243

#### t-Test: Two-Sample Assuming Equal Variances

	Variable 1	Variable 2
Mean	90.5	138.4286
Variance	627.5	2614.286
Observations	6	7
Pooled Variance	1711.201	
Hypothesized Mean Difference	0	
Df	11	
t Stat	-2.08256	
P(T<=t) one-tail	0.030713	
t Critical one-tail	1.795885	
P(T<=t) two-tail	0.061426	
t Critical two-tail	2.200985	

For this analysis, a two-tailed test was used. Based on a  $P(T \leq t)$  two-tail value of 0.061 ( $1 - 0.061 = .939 = 93.9\%$ ) indicates that there is a 93.9% probability that the treatments are different.

### Example 4. Determining the highest yielding cultivar

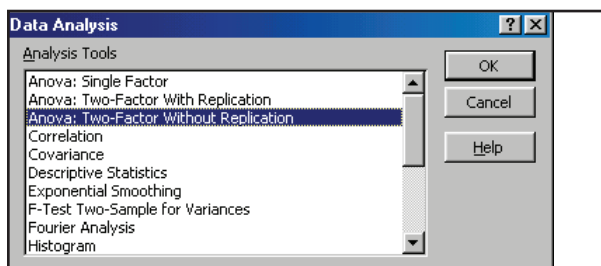
In scientific studies, one, two, or more factors are typically chosen for comparison. In this example, six corn hybrids are compared. Each hybrid is randomly planted in strips in four fields. To solve this problem, an approach for determining the yields of each strip is needed. Yields from strips can be measured with a weigh wagon or with a yield monitor.

If a yield monitor is used, we suggest that you contact an Extension Specialist for assistance. Programs for processing yield monitor data are available at Pierce and Clay (2007). Using a weigh wagon, yield was taken from the harvested strips. The yields from the four replications (the four different fields) were corrected to 15.5% moisture and input into a spreadsheet as shown in Figure 33.5.

	A	B	C	D	E	F	G
1							
2		Variety 1	Variety 2	Variety 3	Variety 4	Variety 5	Variety 6
3	Field 1	126	144	131	150	160	155
4	Field 2	132	149	136	155	158	150
5	Field 3	137	151	144	153	156	158
6	Field 4	155	149	143	162	162	153

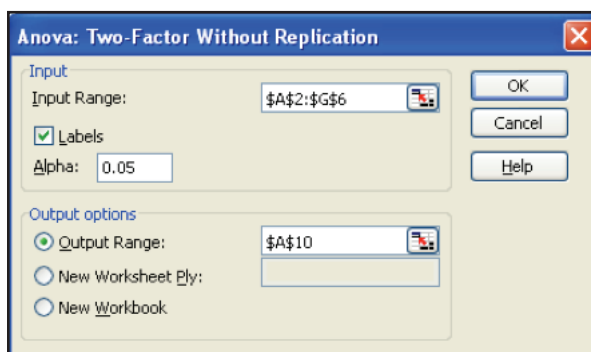
Figure 33.5. Corn yield data from a hypothetical on-farm study that evaluated six different hybrids.

In this analysis, each field will be considered as a block. A block contains all of the treatments. The advantage of using a blocked design is that differences between fields can be removed from the analysis. In this example, the first factor is the treatment and the second factor is blocks. To conduct the analysis, select Tools and ANOVA: Two-Factor Without Replication (Fig. 33.6).



**Figure 33.6. Selecting the statistical program that will be used in Example 3.**

In the ANOVA Two-Factor Without Replication popup, put the cell numbers into the input range (A2:G6 in this example). Labels are checked (Fig. 33.7). The alpha: level that is default is 0.05 or the 95% probability level is accepted by doing nothing. An Output Range A10 (\$A\$10) is selected (Fig. 33.7). Ok is then entered.



**Figure 33.7. Conducting the statistical analysis discussed in Example 3.**

Results of the ANOVA are shown in Figure 33.8. The table indicates that the Columns (the different varieties) have an F value of 11.3866 (cell E29). This is higher than the critical F value of 2.901295 (cell G29). This means that at the 0.05 (or the 95% probability level), there are yield differences between varieties.

In fact, the Probability level (P-value) of 0.000112 (cell F29) indicated that the varieties are different at above the 99% ( $1 - 0.000112 = 0.999888$  which = 99.9888%) level. This is clearly a highly significant difference. Note that the rows (fields) are also different (cells E28:G28). These cells indicate that the fields (as we might expect) are statistically significantly different (at the greater than 95% level, actually  $1 - 0.03542 = 96.458\%$ ) also.

	A	B	C	D	E
10	Anova: Two-Factor Without Replication				
11					
12	SUMMARY	Count	Sum	Average	Variance
13	Field 1	6	866	144.3333	181.0667
14	Field 2	6	880	146.6667	108.6667
15	Field 3	6	899	149.8333	62.96667
16	Field 4	6	924	154	55.2
17					
18	Variety 1	4	550	137.5	156.3333
19	Variety 2	4	593	148.25	8.916667
20	Variety 3	4	554	138.5	37.66667
21	Variety 4	4	620	155	26
22	Variety 5	4	636	159	6.666667
23	Variety 6	4	616	154	11.33333

**Figure 33.8. Statistical results from the hypothetical on-farm corn hybrid study.** The p-values indicated that there is a difference between the hybrids.

	A	B	C	D	E	F	G
26	ANOVA						
27	Source of Variation	SS	df	MS	F	P-value	F crit
28	Rows	315.4583	3	105.1528	3.708729	0.03542	3.287383
29	Columns	1614.208	5	322.8417	11.3866	0.000112	2.901295
30	Error	425.2917	15	28.35278			
31							
32	Total	2354.958	23				

An LSD (least significant difference) can be used to determine if the yields from one hybrid is higher or lower than another. To calculate the LSD value, the critical t value must be determined. This is determined using the command, **=TINV(0.05, degrees of freedom)**. The 0.05 value is the significance level, meaning that we want to be 95% certain that there is a difference between the treatments.

An alternative approach is to look this value up in a t-table (Fig 33.1). In this example, the degrees of freedom is provided in cell C30 (Fig. 33.8) and the mean square error, which is similar to the variance discussed above, is provided in cell D30. The number of replications, mean square error, and t-value are needed to calculate the LSD (Fig. 33.9).

	A	B
34	critical t	=TINV(0.05,C30)
35	LSD (.05)	=B34*SQRT(2*D30/4)

	A	B
34	critical t	2.13145
35	LSD (.05)	8.025237

**Figure 33.9. Critical t value and LSD calculation.** This analysis indicates that if the difference between two hybrids is greater than 8.02 bu/acre, then the yields from the two hybrids are different.

Hybrid 1 averaged 137.5 bu/acre and hybrid 4 averaged 155 bu/ac. The difference between these two hybrids was 17.5 bushels. Hybrid 4 out yielded hybrid 1 because the difference is greater than the LSD value of 8.02 bu/acre (Cell B35 in Fig.33.9).

## Summary

This chapter provides an introduction into on-farm research with examples of how to set up experiments and analyze the resulting data. On-farm research can and should be used to test and evaluate management changes on your farm.

#### Additional information and references

Clay, D.E., S.A. Clay, C.G. Carlson, and S. Murrell. 2010. *Mathematics and Calculations for Agronomists and Soil Scientists*. International Plant Nutrition Institute. Available at <http://ppi-store.stores.yahoo.net/maandcaforag.html>

Clay D.E. and J.F. Shanahan (eds). 2010. *GIS Applications in Agriculture: Nutrient Management for Improved Energy Efficiency*. Volume 2. Available at <http://www.crcpress.com/product/isbn/0849375266>

Davis, B. *Introduction to Agricultural Statistics*. 1999. Delmar Cengage Learning.

Doerge, T.A., and D.L. Gardner. 1999. *The Pioneer Split-planter Comparison Method*. In Clay et al. (eds). *Site specific management guidelines*.

Available at [http://www.ipni.net/ppiweb/ppibase.nsf/\\$webindex/article=9C5B38DE85256965005E6A664E4F30BC](http://www.ipni.net/ppiweb/ppibase.nsf/$webindex/article=9C5B38DE85256965005E6A664E4F30BC)

Pierce F.J., and D.E. Clay. 2007. *GIS Applications in Agriculture*. 2007. CRC Press, Taylor and Francis, New York, NY. Available at <http://www.crcpress.com/product/isbn/0849375266>

Knighton, R.E. 1999. *Setting up On-farm Experiments*. In Clay et al. (eds). *Site specific management guidelines*. Available at [http://www.ipni.net/ppiweb/ppibase.nsf/\\$webindex/article=3DD9EB2C85256966006141B759745B04](http://www.ipni.net/ppiweb/ppibase.nsf/$webindex/article=3DD9EB2C85256966006141B759745B04)

Steel, R.D.G., J.H. Torrie, and D.A. Dickey. 1997. *Principles and Procedures of Statistics: A Biometrical Approach*. Third Edition, McGraw-Hill Publisher.

Wittig T.A., and Z.W. Wicks III. 1999. *Simple On-farm Comparisons*. In Clay et al. (eds). *Site specific management guidelines*.

Available at [http://www.ipni.net/ppiweb/ppibase.nsf/\\$webindex/article=F7F42D9E852569660061A77FDDBC70D3](http://www.ipni.net/ppiweb/ppibase.nsf/$webindex/article=F7F42D9E852569660061A77FDDBC70D3)

#### Acknowledgements

Support for this document was provided by South Dakota State University, South Dakota Corn Utilization Council, USDA-NIFA, South Dakota 2010 research program, South Dakota Wheat Commission, and South Dakota Soybean Board.

---

Carlson, C.G., C. Ren, and D.E. Clay. 2012. *On-farm research and analysis*. In Clay, D.E., C.G. Carlson, and K. Dalsted (eds). *iGrow Wheat: Best Management Practices for Wheat Production*. South Dakota State University, SDSU Extension, Brookings, SD.



## Chapter 34: Seasonal Crop Hazards

Robert G. Hall (Robert.Hall@sdstate.edu)

Every year Mother Nature presents wheat growers, somewhere in South Dakota, with one or more hazards. The purpose of this chapter is to discuss freeze, hail, and flooding hazards.

### *General background on spring and winter wheat growth and development*

The average seeding and growth stage dates for spring and winter wheat are provided in Table 34.1. The planting window for winter wheat generally ranges from early August to early October or from about August 5 to October 5. Historically, about 10% of the crop is seeded by September 5, 50% by about September 17, and 90% by about October 2. Likewise, the planting window for spring wheat generally ranges from early to late April or from April 1 to April 22. Historically, about 10% of the crop is seeded by April 10, 50% by April 22, and 90% by May 10.

**Table 34.1. The average date when 50 and 90% of the spring and winter wheat crops are seeded and when 50% of these wheat crops have reached the boot and heading stages, according to reporting district.** Data obtained from the SD Agricultural Statistics Service (1).

Reporting district	*Average date 50% or 90% of a crop condition or stage is reached							
	Winter wheat				Spring wheat			
	Seeded		Growth stage		Seeded		Growth stage	
			Boot	Head emergence			Boot	Head emergence
	50%	90%	50%	50%	50%	90%	50%	50%
NW	Sep 20	Oct 5	May 29	Jun 11	Apr 22	May 13	June 14	June 24
NC	19	7	27	7	22	9	12	21
NE	15	2	25	7	23	14	11	21
WC	14	Sep 30	24	4	20	16	7	19
C	17	Oct 3	23	3	18	7	8	17

EC	17	4	26	7	17	12	7	15
SW	18	4	23	4	18	11	12	23
SC	14	Sep 29	23	3	15	12	11	19
SE	18	Oct 5	22	2	13	6	2	14

<sup>1</sup>South Dakota Agricultural Statistics Service, 1980-94 average. <sup>a</sup>80% seeded and <sup>b</sup>87% seeded.

This comparison between winter and spring wheat (Table 34.1) is provided to better understand of how crop damage in these two wheat crops differ and how a producer might take advantage of these differences. For example, winter wheat planting starts in September when there is a higher risk of variable sub-soil moisture compared to spring wheat planted in April when moisture in the seeding zone tends to be more uniform. Quick fall establishment of winter wheat is necessary if it is to grow and attain sufficient winter-hardiness to survive the winter. Successful establishment of winter wheat depends on the ability of it to survive the winter.

Winter wheat survival is such a concern for the crop insurance industry in South Dakota that counties in the state have been designated as winter wheat eligible or non-winter wheat eligible counties. The winter wheat in the eligible counties is insured as regular winter wheat. In the non-winter wheat eligible counties, producers plant the winter wheat at their own risk. In the spring, the winter wheat stand is evaluated by an insurance adjuster and if the stand is rated at 90% of the producer's actual production history (APH), the winter wheat crop then meets the criteria for coverage and for insurance purposes and is treated as a *spring wheat* crop for the remainder of the season.

Generally, the exposure time to hazards is longer for winter than spring wheat. Although, spring wheat does not cope with winter survival, it does cope with a delayed planting window. As indicated in Table 34.1, the "Boot" and "Head emergence" dates for spring wheat are about two weeks later than winter wheat. Once winter wheat breaks dormancy and starts spring regrowth and/or once spring wheat emerges following planting, the crops at a given growth stage react similarly to hazards.

**Table 34.2. Approximate temperatures that cause freeze injury to wheat at spring growth stages and symptoms and yield effect of spring freeze injury.**

Growth Stage	Injurious temperature (Two hours)	Primary symptoms	Yield effect
Tillering	<b>12°F</b> or -11°C	Leaf chlorosis; burnt leaf tips, silage odor; blue cast to field	Slight to moderate
Joint	<b>24°F</b> or -4°C	Death of growing point; leaf yellowing or burning; lesions, splitting, or bending of lower stem; odor	Moderate to severe
Boot	<b>28°F</b> or -2°C	Floret sterility; spike trapped in boot; damage to lower stem; leaf discoloration; odor	Moderate to severe
Heading	<b>30°F</b> or -1°C	Floret sterility; white awns or white spikes; damage to lower stem; leaf discoloration	Severe
Flowering	<b>30°F</b> or -1°C	Same as heading stage (above)	Severe
Milk	<b>28°F</b> or -2°C	White awns or white spikes; damage to lower stems; leaf discoloration; shrunken, roughened, or discolored kernels	Moderate to severe

Dough	28°F or -2°C	Shriveled, discolored kernels, poor germination	Slight to moderate
-------	--------------	---	--------------------

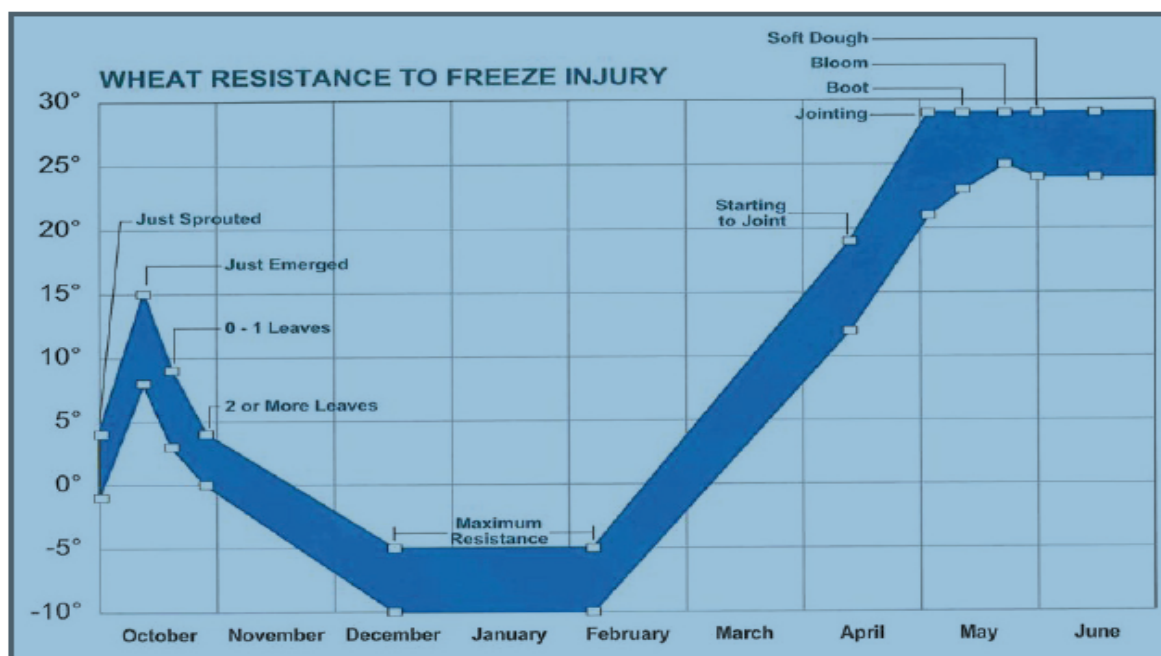
<sup>3</sup> Shroyer, et al. 1995. Kansas State University.

### General background on freeze and frost injury

Wheat injury occurs at those developmental stages that are most sensitive to frost or freezing temperatures (Table 34.2). Generally, winter wheat is resistant to freezing temperatures in the fall and reach maximum resistance from mid-December through mid-February. Thereafter, from late winter to early May the winter wheat plants gradually lose their resistance. Over wheat's life-cycle, no single temperature causes damage; but rather a range of temperatures that is mitigated by many environmental and cultural factors.

Producers should note that Table 34.2 also indicates (1) the approximate injurious temperatures that, when maintained for two hours, significantly affects wheat at given growth stage; and (2) the primary injury symptoms one might observe when evaluating freeze injury. On average, the yield potential of wheat is affected by freezing temperatures from jointing to the milk stage, with the greatest reduction occurring when frost damaged at heading and flowering.

**Figure 34.1. Temperatures that cause freeze injury in winter wheat at different growth stages.** Winter wheat rapidly loses hardiness during spring growth and is easily injured by late freezes. *Adapted from A.W. Pauli.*



### Evaluating crop injury

There are two factors to consider when evaluating wheat frost damage. First, growers should generally wait for at least **3 days of warmer** temperatures before assessing damage. Three days of **warmer** temperatures generally increase the chance the plant will resume growth while cool temperatures will not. Damaged plants must have time to resume growth in order to give any

indication they have the potential to recover. If you assess damage before the plant has time to recover, the damage can be either under- or over-estimated.

Assessments conducted three or more days after frost are common if the severity of the frost is variable or light and one wants to get the best estimate of potential crop recovery. There are cases where crop damage can be evaluated shortly after frost. For instance, in cases where the frost is very severe (mid 20s or lower) and the growing point is near or above the soil surface. In such cases, frost may result in blackened plants or water-soaked main stem growing points—indicating there is little if any chance for new tillers and any compensation for early yield losses.

A second factor in evaluating spring wheat frost damage is to dissect and inspect the growing points of the lower main stems. The growing point is a region of actively dividing cells located on the main stem and is enclosed by leaf tissue. The growing point is located immediately above the topmost node on the main shoot. This growing point is critical because it initiates the development all of the shoot, including leaves, tillers, and terminates in the wheat inflorescence (flower head) or spike. Damage to the growing point will either kill the seedling or severely inhibit or slow its growth.

As the seedling emerges, the growing point is located at the crown or about ¾-inch above or below the soil surface. Later, at stem internode elongation (jointing stage), the growing point is eventually elevated above ground. An analogy would be the elevation of a radio antenna (stem), upward in sections (internodes), until the antenna tip (spike or head) is fully elevated.

At jointing, wheat generally tolerates temperatures from the lower to upper 20s for some time; however, if temperatures fall to the lower 20s for two hours or longer, significant damage can occur. Once temperatures approach the lower 20s, damage is directly related to length of time. If the exposure is two hours or less, the damage will likely be less than if exposure is more than two hours. If frost occurs as the elongating plant reaches the boot stage, damage to the flag leaf, stems, and the developing head can occur if the temperature drops to the upper 20s.

Assess damage to the growing point by splitting the stem down the middle and looking for the growing point region immediately above the topmost node. The growing point looks like an elongated and immature spike sitting atop the topmost node. Tissue in this region should be *firm* and *yellowish to white* in color. Mushy tissue or discolored tissue (brown and/or black) are typical signs of freeze injury. Generally, the amount of damage is dependent on the temperature and duration.

At temperatures above 28° F the amount of damage to the growing point is generally low to moderate because the growing point is protected by the surrounding tissue and/or location of the growing point is below the soil surface. At 28° F or lower, the amount of damage to the growing point increases; depending on how low and fast the temperature drops, and the health of the plant as frost occurred. Moreover, the risk of freeze injury increases significantly the farther the temperature drops below 28°F, even if the growing point is below the soil surface.

All crop producers agree that assessing freeze injury is an emotional experience. Again, remember that to accurately assess the damage you need to wait a few days. Often the most vivid symptoms of freeze injury in wheat immediately following the frost is the appearance of the leaves. Generally, water soaked areas will appear on the leaves and in turn will turn brown in a few days if the frost event was moderate.

In cases of severe freeze the leaves may appear black and/or may be disintegrating. Even though a spring frost may result in leaf defoliation, defoliation itself is not always the most important factor. A major factor in the assessment of spring freeze damage in wheat may be to

determine the ability of the damaged stand to produce additional tillers that will potentially produce a harvestable head that compensates for any yield loss as the result of frost damage.

Generally, following a moderate freeze, new growth including leaves or tillers will start to appear in about 3 to 10 days if temperatures recover enough to spur growth. In contrast, with a *severe* freeze, there is less chance for regrowth recovery that compensates for yield losses. If the damage occurs before jointing, there is a greater chance of the crop recovering to produce an economic yield than if the frost is severe and occurs following jointing or later. Two excellent sources of information regarding frost or hail damage to wheat can be found in Shroyer et al. (1995) and Klein and Lyon (2006).

### ***Hail injury***

Hail, like frost, is a weather event that often defoliates the wheat crop. The ability of the hailed wheat to recover is very similar to its ability to recover following frost. However, following hail, the plant must cope with breakage or bruising that may occur to the stem. Again, when assessing damage use the same general guidelines listed under frost damage. In many cases, the leaves may be stripped from the plant and recovery is generally possible if the hail occurs at early growth stages.

Should hail occur later, then recovery is possible as long as the stem is not damaged or broken below the spike. Leaf defoliation may result in a significant loss in photosynthetic surface that contributes to yield. Leaves split lengthwise by hail can still contribute to yield since much of the yield produced in the leaves can still move to the ear. The monetary assessment of hail damage in wheat is very complex and should only be determined by a trained crop adjuster.

Often damage claims in wheat are deferred to the end of the season in order to account for (1) additional tillers that might develop and contribute to yield, and (2) and for additional yield losses that might occur before the damaged crop is finally harvested.

In summary, generally wait for at least 3 days of warm weather before making a management decision. If frost damage is light and variable, there is a chance that regrowth in the form of new tillers will help compensate for early yield losses. If however, damage is severe and/or at a sensitive stage, there is less chance for recovery and compensation for early yield losses. In frost damaged or hailed wheat fields, it is common to defer the evaluation of any losses until harvest is complete. Therefore, it is strongly suggested in the event of a frost or hail event that producers contact their crop insurance agent as early as possible.

### ***Flood damage***

Crop damage as the result of flooding is generally the result of oxygen (O<sub>2</sub>) deprivation to the growing plant. In some cases, plants can tolerate flooding as long as the plants are not totally submerged. Generally, as the amount of plant tissue submerged increases, the risk of oxygen deprivation increases to levels that are lethal to the plant. There are numerous references to crop damage to flooded crops.

In cases where wheat is totally submersed in warm water in the mid-70s F° death may occur within 24 hours, while totally submerged plants in water temperatures of 50s F° or below may survive a few hours longer. It is not uncommon for partially submerged wheat plants to survive flooding three to four days if the water temperatures are relatively cool. In many cases, yield losses ranging from 20- to 50% have been reported in the literature where waterlogging of the soil occurred for 10 days or more.

**Additional information and references**

South Dakota—seeding to harvest. 1995. South Dakota Agricultural Statistics Service.

Shroyer, J.P., M.E. Mikesell, and G.M. Paulsen. 1995. Spring freeze to Kansas wheat. C-646. Agricultural Experiment Station and Cooperative Extension Service, Kansas State University, Manhattan, KS. Available at [www.ksre.ksu.edu/library/crpsl2/c646.pdf](http://www.ksre.ksu.edu/library/crpsl2/c646.pdf)

Klein, R.N. and D. J. Lyon. Revised 2006. Freeze injury to Nebraska wheat. EC132. University of Nebraska—Lincoln Extension, Lincoln, NE. Available at <http://cropwatch.unl.edu/web/cropwatch/archive?articleID=4532110>

Simmons, S.R., E.A. Oelke, and P.M. Anderson. 1995. Growth and development guide for spring wheat. FO-2547-D. Minnesota Extension Service, University of Minnesota, College of Agriculture. Available at <http://www.extension.umn.edu/distribution/cropsystems/dc2547.html>

Wiersma, J. 2009. Losses in wheat due to flooding and waterlogging. Minnesota Extension Service, University of Minnesota. Minnesota Crop News, June 30, 2009.

**Acknowledgements**

Support provided by the South Dakota Wheat Commission, SDSU Extension, and USDA-IPM.

---

Hall, R.G. 2012. Seasonal crop hazards. *In* Clay, D.E., C.G. Carlson, and K. Dalsted (eds). iGrow Wheat: Best Management Practices for Wheat Production in South Dakota. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.



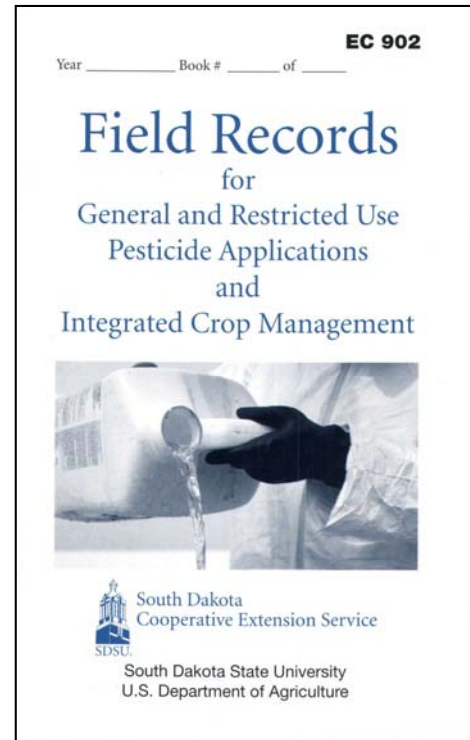
## Chapter 35: Recordkeeping

Jim Wilson ([James.Wilson@sdstate.edu](mailto:James.Wilson@sdstate.edu))  
Kurtis D. Reitsma ([Kurt.Reitsma@sdstate.edu](mailto:Kurt.Reitsma@sdstate.edu))

Recordkeeping is an important component of all crop production systems. The time that is spent maintaining careful records can help improve the production, profit, and overall efficiency of the production enterprise. Records provide historic information needed to identify successes and failures.

Records should be as detailed and complete as possible. Some basic elements of records include field location, crop type, hybrid number, genetic enhancements, soil type(s), previous crop, tillage, planting information, soil test and fertilizer/manure applications, pesticide applications, and harvest information.

Scouting maps and the results of soil and manure tests should be attached or included in records. The location of problem areas (previous weed, insect and disease as well as wet and saline spots) within the field should be identified and the area marked on a map. Maintain a latitude–longitude record of the location of drain tile lines if they have been installed in the field. If available, daily or monthly weather records should be attached to the yearly record, as weather is one of the most influential yet uncontrollable variables that can impact crop yield.



### ***Recordkeeping requirements of private pesticide applicators***

Federal law requires that all private pesticide applicators keep the following records of the applications of all restricted-use pesticides (RUP).

1. **The brand or product name of the RUP and its EPA registration number.**  
Federal law only requires you record RUP applications, but general use pesticide applications should be documented as well.
2. **The total amount applied.**  
Record the total quantity of the product used—not the quantity after water or other substances were added. Amount does not refer to percent of active ingredient. Use the pesticide label for reference and record the amount in quantities similar to label language. For example, if the label states the pesticide is to be measured in pints or ounces, then record the amount in that measurement.
3. **The size of the area treated.**

This information should be recorded in a unit of measure such as acre, linear feet, bushel, cubic feet, square feet, number of animals, etc., which is normally expressed on the pesticide label in reference to this application being made. For special applications such as weed wicks or band applications, record the total area covered. For example, if an 80-acre field is treated using a band application, the entire 80 acres would be recorded as the “size of area treated.”

4. **The crop, commodity, stored product, or site to which the pesticide was applied.**  
Refer to the pesticide label for guidance if you are unsure how to record this information.
5. **The location of the application.**  
Record the location of the treated area, not the address of the farm or business. Your goal is to be able to allow an individual who is not familiar with the area to identify the exact location of the application two years later. The law allows only the following location designations:
  - a. County, range, township, and section.
  - b. Maps or written descriptions.
  - c. A USDA identification system such as those used by the Natural Resources Conservation Service or the Consolidated Farm Service Agency (formerly SCS and ASCS), which involves maps and a numbering system to identify field locations.
  - d. GPS coordinates.
  - e. The legal property description.
6. **The month, day, and year of the application.**
7. **The applicator’s name and certification number.**

Federal law requires that these records be recorded within 14 days of application and kept for a minimum of 2 years. RUPs may only be purchased and applied by a certified applicator. All RUPs will clearly state “restricted use” on the label. Additional information on pesticide and general field recordkeeping is available from SDSU Extension Regional offices or:

SDSU Extension

<http://www.sdstate.edu/ps/extension/pat/pesticide-record.cfm>

South Dakota Department of Agriculture

[http://sdda.sd.gov/Ag\\_Services/Agromony\\_Services\\_Programs/Pesticide\\_Program/Pesticide\\_Recordkeeping.aspx](http://sdda.sd.gov/Ag_Services/Agromony_Services_Programs/Pesticide_Program/Pesticide_Recordkeeping.aspx)

### ***Recordkeeping requirements of commercial pesticide applicators***

South Dakota Administrative Rules (ARSD 12:56:07:01) lists the items required for commercial pesticide applicator records.

Records do not need to be kept as a single document. They may consist of several documents, provided the documents have been completed by the applicator and the required information has been recorded. If the records are placed in a book or file, the list of supplemental

document locations must be attached. Record information may be coded, provided an explanation of the codes is attached to record.

A commercial applicator must record the following information for each application by the close of each business day. *All application records must be kept a minimum of 3 years.*

1. The name and address of the person for whom the pesticide was applied.
2. The location of the land or property where the pesticide was applied.
3. The pest to be treated.
4. The acreage, area, or number of plants or animals treated or other appropriate description.
5. The year, month, day, and time the pesticide was applied.
6. The person or firm who applied the pesticide.
7. The trade or brand name and common name of the pesticide applied.
8. The company name appearing on the product label.
9. The weather conditions at the time of application, including direction and estimated velocity of the wind and the temperature at the time the pesticide was applied. (This requirement does not apply to application of baits in bait stations or pesticide applications in or immediately adjacent to structures.)
10. Amount of the pesticide applied and concentration in pounds or gallons per unit or percentages of active ingredient per unit of the pesticide used.
11. Specific crop or designated site or commodity to which pesticide application was made.
12. Name and address of the applicator.

#### *Useful links*

- [SDSU Private Applicator Restricted Use Pesticide Recordkeeping](http://www.sdstate.edu/ps/extension/pat/index.cfm)  
<http://www.sdstate.edu/ps/extension/pat/index.cfm>
- For the following sources of information, use the South Dakota Department of Agriculture Pesticide Program website:  
[http://sdda.sd.gov/Ag\\_Services/Agronomy\\_Services\\_Programs/Pesticide\\_Program/Pesticide\\_Recordkeeping.aspx](http://sdda.sd.gov/Ag_Services/Agronomy_Services_Programs/Pesticide_Program/Pesticide_Recordkeeping.aspx)
  - [SDDA: Compliance Policy Guide for Commercial Applicator Records](#) (pdf)
  - [USDA Pesticide Recordkeeping Program](#) (link)
  - [USDA Pesticide Recordkeeping Requirements for Certified Private Applicators of Federally Restricted Use Pesticides](#) (pdf)
  - [USDA Restricted Use Recordkeeping Inspection](#) (pdf)
  - [USDA Guidance for Using GPS Coordinates to Record Locations under the Federal Pesticide Recordkeeping Regulations](#) (pdf)

**Additional information and references**

Deneke, D., and R. J. Wilson. 2010. Field records for general and restricted use pesticide applications and integrated crop management. EC902. South Dakota State University, SDSU Extension, United States Department of Agriculture, Brookings, SD. [http://pubstorage.sdstate.edu/AgBio\\_Publications/articles/ec902.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/ec902.pdf)

Pesticide programs – recordkeeping requirements. South Dakota Department of Agriculture, Division of Agricultural Services, Office of Agronomy Services.

[http://sdda.sd.gov/Ag\\_Services/Agronomy\\_Services\\_Programs/Pesticide\\_Program/Pesticide\\_Recordkeeping.aspx](http://sdda.sd.gov/Ag_Services/Agronomy_Services_Programs/Pesticide_Program/Pesticide_Recordkeeping.aspx)

Recordkeeping manual for private pesticide applicators. 2010. United States Department of Agriculture, Agricultural Marketing Service – Pesticide Records Branch.

<http://www.ams.usda.gov/AMSV1.0/getfile?dDocName=STELPRD3342981>

---

Wilson, J., and K.D. Reitsma. 2012. Recordkeeping. *In* Clay, D.E., C.G. Carlson, and K. Dalsted (eds). iGrow Wheat: Best Management Practices for Wheat Production in South Dakota. South Dakota State University, SDSU Extension, Brookings, SD.

Name									
Address									
City			State			Zip			
Certification Number:					<input type="checkbox"/> Private <input type="checkbox"/> Commercial			Exp. Date:	
Field Name								Acres	
Quarter:			Section:			Township:			Range:
Soil Type:									
-----Crop Information-----					-----Soil Fertility-----				
Previous Crop					Date of Sampling				
Tillage					Soil Test Results			Pre-Sidedress N Test	
Residue % at Planting					NO <sub>3</sub> - N		NO <sub>3</sub> - N		
-----Planting Information-----					P				
Hybrid:					K				
Maturity		RM:		GDU:		pH			
Yield Goal					OM				
Planting Date					Other				
Planting Depth					----Nitrogen Credits from Previous Year----				
Moisture at Planting					Manure N Credit			Legume Credit	
Planting Population									
Actual Population					*Attach Soil and Manure Test Results				
-----Fertilizer/Manure Applications-----									
Date	Fertilizer Grade – or -- Type of Manure		-----Nutrients Applied-----				Cost/Acre		
			N		P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O			Other
Summary for crop									
-----Herbicide/Insecticide/Fungicide Applications-----									
Date	Brand Name		EPA Registration Number (From Label)		Target Pest		Amount Used		Acres Applied
-----Harvest Information-----									
-----Acres with Percent Lodging-----				Date of Harvest					
0-25%	25-50%	50-75%	75-100%	Estimated Yield					
				Actual Yield					
----Aflatoxins----				Harvest Loss					
Black Light Test		<input type="checkbox"/> Positive	<input type="checkbox"/> Negative	Moisture % at Harvest					
If aflatoxin is suspected, submit sample for laboratory analysis regardless of black light test results.				Date of Sale					
				Price Received					